

LECTURES

ON

NATURAL AND EXPERIMENTAL PHILOSOPHY,

CONSIDERED IN IT'S PRESENT STATE OF
IMPROVEMENT.

DESCRIBING, IN A FAMILIAR AND EASY MANNER,
THE PRINCIPAL PHENOMENA OF NATURE;

AND SHEWING,

THAT THEY ALL CO-OPERATE IN DISPLAYING
THE
GOODNESS, WISDOM, AND POWER OF GOD.

BY GEORGE ADAMS,

Mathematical Instrument Maker to His Majesty, and Optician to His Royal
Highness the Prince of Wales.

VOL. II.

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1794.

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THAT THEY ARE CONNECTED BY A BRILLIANT

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BY GEORGE ADAMS.

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LECTURES ON NATURAL PHILOSOPHY.

OF THE NATURE AND PROPERTIES OF WATER.

LECTURE XII.

THE study of nature is as much distinguished from other subjects by the importance of it's matter, as by the variety of it's topics. But amidst all this variety, the *true philosopher* is interested by the objects, *only* in proportion to the indication they afford of design and providence in the government of the world. This consoling testimony you will find spread abundantly over the face of nature; it is every where distributed into masses and portions, according to the nature of the subject. Every object we meet with, great or small, bears the stamp of an ALL PERFECT CREATOR, is a mark of his wisdom, a monument of his power, and a proof of his goodness: many instances of the order, beauty, harmony, and proportion, in the works of nature, have been exhibited in the foregoing Lectures. The subjects that I am going to treat of in this Lecture will furnish us with more.

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As you advance in the knowledge of nature's varieties, your mind will be opened, and you will find fresh ornament in truth, fresh dignity in devotion, and fresh reason in religion. By thus employing your contemplations, you will not only enjoy the purest pleasure, but you will learn in the scriptural phrase to *walk with God*, and cherish towards him a certain loyalty of heart that brings all the ardours and sensibilities of our nature to the side of religion.*

From treating of air and fire, I now proceed to consider the nature of *water*, whose wonderful properties are alone an abundant source of knowledge. It is a substance that in a certain degree of heat is *fluid*, in a less it is *solid*, and with a greater degree is convertible into an *elastic vapour* of incredible force. It is capable of dissolving all kinds of salts, of absorbing and detaining in its substance the air of the atmosphere, of being elevated and suspended in immense quantities in the regions thereof. In the general œconomy of nature, water promotes solution, separation, association, and subsidence. It is a substance which enters into so many operations both of nature and art, that to give you a full description of its properties would include those of most other substances.

Its weight is used as the measure of *specific gravity*. Its *temperature* at the changes from solidity to fluidity, and from thence to the elastic state, are taken for the fixed points of thermometers.

Water constitutes not only the principal part of blood, milk, wine, oil, and other fluids, but also enters in a large proportion into the constitution of the solid parts of all animal, vegetable, and of many mineral substances.

Water

* Looker on, No. 12.

Water serves to the art and navigation of man, as air serves to the wings of the feathered species. It is the easy and speedy medium, the ready conduct and conveyance, whereby all redundancies are carried off, and all wants supplied. It makes man as it were a denizen of every country on the globe. It shortens every distance, and ties the remotest regions together. It carries and communicates the knowledge, the virtues, the manufactures and arts of each clime to all. It gives springs to industry, energy to invention.

OF THE COMPOSITION AND DECOMPOSITION OF WATER.*

Until very lately this fluid has been always considered as a simple substance. The experiments of Mr. Lavoisier, which I have related to you in a former Lecture, has induced many to consider it as a compound, consisting of inflammable and vital airs: in other words, that the whole mass of any quantity of water may be converted into inflammable and vital air: and that the combustion of these airs produces a volume of water proportioned to the weight of the airs employed in the experiment. Though I have already shewn you, that the experiments of Mr. Lavoisier and the French chemists by no means warrant the deductions they have made from them, yet as they have made these experiments the basis of a new system of chemistry, and have invented and appropriated a new set of terms, in order to propagate it more readily, it will be necessary in this place further to investigate the subject.

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* Dr. Priestley's Observations and Experiments on Air. Keir's Chemical Dictionary.

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That their experiments do not authorize, their conclusion, appears from this, that when vital and inflammable airs are decomposed by heat, we find both from the experiments of Dr. Priestley and the French chemists, that the *nitrous acid* is always formed; and though this acid has been said to come from the phlogisticated air, which could not be wholly excluded in the process, there are several considerations that prove the acid could not have this source; the more so, as this process does not at all decompose, or in the smallest degree affect phlogisticated air.

In what ever manner, says Dr. Priestley, vital and inflammable air be made to unite, *some acid* is produced, and in no case *pure water*. If iron, containing phlogiston, be heated in vital air; or if precipitate per se, containing vital air, be heated in inflammable air, fixed air is always formed; whereas, according to the modern hypothesis, water ought only to be produced in both cases.

Water, they assert, is always decomposed when it is made to pass over red-hot iron; the iron according to their opinion imbibing the acidifying principle, the remainder going off in inflammable air. Now it is unfortunate for this hypothesis, that no substances will answer for this experiment, except such as have always been considered as containing phlogiston. It is therefore most probable to suppose, that the inflammable air is formed by the phlogiston from these substances, *water* being the base; and that if any part of the substance remain and acquire weight, it receives that additional weight from water only.

That phlogiston is an element of water seems probable, 1st, because water conducts electricity like metals and charcoal, into which the same principle enters; and 2dly, because when fresh distilled it attracts vital air from the atmosphere, which is
also

also a property of other bodies containing phlogiston. In this sense it may be said to contain both the principles of the new theory, though it is a sense that entirely overthrows that theory.

Without however entering more minutely into this investigation, it is sufficient to observe, that the formation of nitrous acid from the combustion of inflammable and vital airs, clearly proves *that water is not a compound of these airs; or that it is only so, in a certain proportion of these ingredients, while another proportion yields nitrous acid.*

For by admitting the formation of the nitrous acid from the same fluids, the argument for the composition of water drawn from the complete substitution of an equal weight of water to that of the airs which disappear by combustion, no longer exists; and as the appearance of a large quantity of water in these experiments is readily explained from the precipitation of the water which is known to be suspended in these elastic fluids, or which even make a necessary part of their composition, no fact remains on which the hypothesis of the formation of water from any proportion of inflammable and vital air is grounded. The *fundamental* experiment of this doctrine, namely, the equal substitution of water, and nothing but water, to the airs which disappear, being removed, the *structure* with all its ornaments must fall, and no other vestige will remain but the ingenuity and skill of the artist.

OF WATER IN A FLUID STATE.

Water is considered as a pellucid, colourless fluid, tasteless, and without smell, nearly incompressible, and elastic only in a small degree. It adheres to the substance of most bodies, but penetrates and incorporates with a still greater number. It

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extinguishes flame. It is capable of passing through various states of aggregation, from the solidity of ice to the tenuity of vapour.

Many have considered *ice* as the natural state of water, and the fluidity thereof as a state of violence, or as ice kept in continual fusion, and returning to it's former state, when deprived of a certain quantity of fire. Were you to define lead and water, you would call one a solid, the other a fluid, esteeming these their natural condition. Yet if water be not acted upon and combined with a certain quantity of fire, it becomes a solid. We call that *state* natural which falls immediately under our observation. If we had lived in *Saturn*, we should have given but one name to ice and water, although we might now and then have seen it liquified in summer; and on the other hand, had we been born in *Mercury*, we should have deemed lead a fluid.

The particles of water, though moveable amongst themselves with the greatest ease, yet adhere together with a certain force; thus a drop of water remains suspended at the end of the finger, although the inferior particles only touch other particles of the same fluid. This adherence of the particles prevents small needles, or very thin plates of metal from sinking therein, as they resist division more than the excess of the specific gravity of these bodies over a relative volume of water.

Water can only be compressed in a very small degree, so small that it may in general be considered as incompressible, as will be evident to you by considering the Florentine experiment which I have already mentioned to you. That it is, however, compressible in a small degree, may be proved by an easy experiment: put water into a bottle with a stem nicely graduated, observe the degree at which it stands, and place the bottle under the receiver of an air-pump, and exhaust the air therefrom; when
the

the pressure of the air is removed, the fluid will rise a little.

We have no fluid more subtil and penetrating than water, except fire; it enters into the minutest particles and pores of matter, the finest vessels of animals, and the smallest tubes of plants, and will pierce through substances which will detain air itself. This penetrative power of water, together with it's smoothness and lubricity, renders it a fit *vehicle* for the easy conveyance of the nutritious matter of all bodies.

It enters into the composition of all the substances belonging to our earth. There is probably no substance, whether animal, vegetable, or mineral, without it. Every being with life, in a great degree lives by it; and whatever grows, through it receives it's growth; and wherever it enters, according to the ~~oeconomy~~ economy of providence, it promotes and sustains life, preserving all material nature in their proper classes of existence. It bears a part in the formation and decomposition of all the mineral kingdom. It is necessary to the free exercise of the functions of the animal body, and hastens and facilitates the destruction of both vegetables and animals as soon as they are deprived of life. But whether you consider it as productive of health to animals and vegetables, as requisite to the beauty and existence of the earth, or as one of the great powers by which God works in the sustentation and action of the whole universe; you cannot but admire the sublime propriety with which, as a sensible image, it is used in the sacred scriptures, to represent divine truth, and the holy influence of our GOD and SAVIOUR.

PRESENCE OF WATER IN THE ATMOSPHERE.

So great is the necessity, use, and importance of this fluid in all things, that some ancient philosophers

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were impressed with a notion of it's being the first principle of universal life. It seems to be universally diffused. And it will be easy to convince you of the great quantity contained in the air. You may be said to walk in an ocean; the water indeed of this ocean does not become the object of our senses, we cannot see it, nor, whilst it continues thus sustained in the air, do we feel that it wets us; but it is still water, though it is neither visible nor tangible; just as sugar, when dissolved in water, is still sugar, though we can neither see it, nor feel it. Some are puzzled to find water enough to form an universal deluge; * to assist their endeavours it may be remarked, that were the whole precipitated which is contained in the air, it might probably be sufficient to cover the surface of the whole earth to the depth of above 30 feet. If a bottle of wine be fetched out of a cool cellar in the hottest and driest day of summer, it's surface will soon be covered with a thick vapour, which when tasted appears to be water. This watery vapour cannot proceed from any exudation of the wine, through the pores of the bottle, for the glass is impervious to water, and the bottle remains full, and when wiped dry it is found to weigh as much as when taken out of the cellar. The same appearance is observable on the outside of a silver, or any other metallic vessel, in which iced water is put in the summer time; and it is certain, that the water which is condensed on the surface of the vessel does not proceed merely from the moisture exhaled by the breathing of the people in the room, where you may notice the experiment, because the same effect will take place if the vessel be put in the open air. Water which is cooled by the solution of any salt, or even spring-water which happens to be a few degrees colder than the air, produces a similar condensation of vapour

* Watson's Chemistry, vol. iii, p. 87.

vapour on the outside of the vessel in which it is contained. These, and other appearances of the same kind are to be explained on the same principle. When warm air becomes contiguous to the outward surface of a vessel containing cold liquor, the fire by which the water is suspended in the air, and quits and passes through the vessel into the liquor, to restore it to the temperature of the place, and the water ceasing to be suspended in the air, attaches itself to the surface of the cold vessel.

Another method of proving the existence of water in the clearest air, is, to observe the increase of *weight*, which certain bodies acquire by exposure to the open air. Dr. Watson put into the open air eight ounces of salt of tartar, which had been well dried on a hot iron; the day was without a cloud, the barometer at 30 inches; in the space of three hours, from 11 to 2 in the afternoon, the salt had increased two ounces in weight. In the course of a few days it's weight was increased to 20 ounces; it was then quite fluid, and being distilled, it yielded a pure water, equal in weight nearly to the increase it had acquired from the air. Strong acid of vitriol is another body, which absorbs humidity strongly from the air. An ounce of this acid has been observed to gain in twelve months above six times it's own weight.

The increase of weight experienced by the human body (in many cases from the water, which the pores of the body suck in from the air) is another very sensible proof of the great quantity of water suspended in the air. The Bishop of Llandaff mentions, among many instances, one of a lad, at Newmarket, a few years ago, who having been almost starved, in order that he might be reduced to a proper weight for riding a match,
was

was weighed at nine o'clock in the morning, and again at ten, and was found to have gained near thirty ounces in weight in the course of an hour, though he had drank only half a glass of wine in the interval. The wine, probably, stimulated the action of the nervous system, and incited nature, exhausted by abstinence, to open the absorbent pores of the whole body, in order to suck in some nourishment from the air. It is well known, that persons, who go into a warm bath, come out several ounces heavier than they went in, their bodies having imbibed a correspondent quantity of water. Part of the utility of medicated vapour-baths depends on this principle of imbibition by the pores.

There is a circumstance of importance concerning the human frame, which seems to have escaped the attention of most physiologists, namely, the nature of animal moisture, and the means by which it is supported and kept up. I have shewn you, in this Lecture, what a quantity of moisture the human frame will take from the air; and this might have been supported by a greater variety of facts, if there had been any further necessity for proof. There are several considerations independent of these facts, which will of themselves lead you to conclude, that animal moisture cannot be altogether supported, or accounted for, by what is received internally, as meat and drink; and you will be led to think that the greater part is received from the atmosphere; and that it is probable that the human frame has a power of decomposing some of the aerial fluids, which abound in the atmosphere, and procuring water from them.

The considerations alluded to above, are, that the fluids constitute more than half the bulk and matter of the animal frame; that the basis of these fluids

fluids is water ; that they have a strong vaporific tendency, and are continually heated to 96 degrees ; that a vast surface is exposed to the drying power of the air, not only the whole external surface, but that also of the lungs ; and that every vital fibre and particle is not only exposed to this heat, but also to the motion arising from the rapid circulation of the system.

If to all these circumstances, we take in the great heat to which the body is exposed in warm climates, I think we may, with little hesitation, say, that if the same quantity of water, that is contained in the human frame, were exposed to as large a surface of air, more than one half would be evaporated in 24 hours ; for you are to consider that moisture can transpire through our skin ; and that the skin is always moist, and is continually acted upon by animal heat, the air, and the general circulation ; and that without a continued and successive supply of moisture, the skin would be quite parched up.

Add to this, the immense discharges which are constantly issuing out of the human system, by insensible perspiration, by the great discharges from the lungs, by the natural evacuations, by urine, saliva, &c. Take these altogether, and I think it will be impossible for you to conceive these are all supplied by the mouth.

Mr. Harrington says, that he has often, in winter, examined his evacuation by urine, and found it to exceed in quantity, the moisture received into the system by the mouth. Whence then could the superabundant quantity arise ? and what supported the other evacuations ? what under a heat of 96° kept every minute part moist, soft, and pliable ? Many more facts might be adduced in support of this opinion ; but for them I must refer you to your own observation, and Mr. Harrington's work.

OF WATER AS MIXED AND COMBINED WITH BODIES.

You may consider the water, that is in bodies, in two states, either that of simple *mixture*, or that of *combination*.

In the first state, it renders bodies humid, is perceptible to the eye, and may be disengaged from them with facility.

In the second state, it exhibits no character whereby you can discover that it is thus combined. It exists in this form, in crystals, salts, plants, animals, &c.

Water, existing in a state of combination, concurs in imparting to them hardness; and the transparent salts, and most stony crystals lose their transparency, when they are deprived of the water of crystallization. Many bodies are indebted to water for their fixity; the acids, for example, only acquire fixity by combining with water. Water, when mixed with earth or ashes, is formed into a vessel, which when baked will bear the utmost force of the hottest fire that art can contrive. Thus you see a body, whose fluid and dissolving qualities are so obvious, giving consistence and hardness to all the substances of the earth. In this state nature often unites it to bodies, with which art has not yet learned to make it enter into combination.

Pure water will, indeed, unite immediately only with a certain number of substances; but after being united with these, it becomes capable of dissolving other substances in a succession, whose limits we cannot determine, because the further we advance in the knowledge of substances, the greater reason we have for perceiving our ignorance of the number which exist distinctly, and of the intimate ingredients even of those that are known.

known. *Water* is the base of all *menstrua*: we concentrate them to a certain point by evaporation; but beyond this point the liquid either produces nothing but vapour, or escapes entirely. An essential part of the art of *chemistry* consists in the composition of *menstrua*, and in the precipitations operated therein: in these processes water itself often enters into new combinations. If, in his operations, the chemist falls upon any lucrative process, of which he himself is ignorant of the intimate causes; he makes a *secret* of it. But how many such secrets are to be found among the operations of nature? How many that will be concealed from us for ever, because the primitive substances are arrived at a state that cannot be changed by the agents of the present operations in nature.

When water, by a succession of dissolutions, contains different substances, they may be successively precipitated, in two ways, by the dissolution of new substances, or by the emission of expansible fluids, some of whose ingredients were united with the substances in the liquid. Ancient chemists knew scarce any thing of this last process, nor of the various combinations of fire and light. It is to modern discoveries on these heads, that we are indebted for the present advancement of these sciences; but if the chemist, in these pursuits, neglects the study of meteorology and geology, both for directing his investigations of the nature of expansible fluids, and appreciating his decisions on the intrinsic nature of substances, he will run the risk of accrediting errors by the very facts which should have separated him from them. *

Water may be considered as a kind of general cement. The stones and salts, which are deprived of

* See De Luc's Letters, dans le Journal de Physique, for 1790-91-92, &c.

of it, become pulverulent, and fall away into a mass of shapeless dust. Water facilitates the coagulation, re-union, and consistence of the particles of stones, of salts, &c. as you also see in the operations performed with plasters, lutes, mortar, &c.

The stock of water afforded by the driest bodies is surprising; hartshorn kept forty years, and thereby become as hard and dry as any metal, so that if struck against a flint, it would give sparks of fire; upon being distilled, afforded one eighth part of it's quantity of water.

For a considerable time water was thought to be a fluid earth. The earthy residue, left after the distillation, trituration, and putrifaction of water, gave credit to the opinion that it was convertible into earth. Mr. Lavoisier has shewn, that this earth arises from the wear of the vessels; and Scheele has proved the identity in the nature of the earth with that of the vessels in which the operations were made.

In a fluid state water combines so easily with other substances, that it is never to be found in a pure state; the most genuine is mixed with exhalations, and dissolutions of various kinds. Rain-water, which is a fluid of nature's own distilling, and which has been raised so high by evaporation, is nevertheless a very mixed substance, impregnated with exhalations of all kinds; salts, sulphurs, and metals, are combined with it. Mr. Chaptal, from experiments made at Montpellier, found rain-water in stormy weather more impure than that which came in gentle showers; the water which falls first, is less pure than that which falls after several hours or several days rain: that the water which fell when the wind blew from the sea to the southward, contained sea-salt, while that which was produced by a northerly wind did not contain
a single

a single particle. The water caught pouring from the tops of houses is impregnated with the smok of the chimnies, the vapours of the slates and tiles, and with such impurities as birds and animals have deposited there. It is the same with river-water; plants, minerals, and animals, all contribute their share to add to it's impurities; wherever the stream flows, it receives a tincture from it's channel. Of the various river-waters, those of the Indies and the Thames are said to be the lightest and most wholesome.

Waters in general are supposed to be more pure as they are more soft; snow-water is very soft; rain-water comes next to it; spring-water, though the clearest and most tempting of all to look at, is the least pure, and of all others the least fit for common use. Spring-water is pure, or polluted, in proportion as the earth through which it streams is more or less impregnated with sulphur, salts, arsenic, minerals, &c. Those that are strained through a sandy soil, free from saline or metallic substances, are the purest. The eye is no adequate judge on this occasion. It will indeed teach you not to drink or use foul or dirty water, but it will leave you in the dark as to those contents of the water which may be suspended in it imperceptibly. Transparency is certainly a very agreeable quality in water, but cannot be relied on as a proof of salubrity, for sea-water is as transparent as that which is fresh. The water of stagnate lakes and pools is in general very impure, and may be considered as a jelly of floating insects, the whole teeming with shapeless life, growing more fruitful by increasing putrifaction, forming a mass of corruption, displeasing to the sense and injurious to the health.

The atmosphere itself may be looked upon not only as the general receptacle of all aqueous vapours, but likewise of all mineral exhalations of the

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the steams which are constantly arising from the perspiration of whatever enjoys animal or vegetable life, and from the instantaneous putrescence of those substances when deprived of life; of the smaller seeds of terrestrial and aquatic plants, of the eggs of an infinite species of imperceptible animalcules, of the acids and oils separated by combustion from all sorts of fuel, of the matter of light, of electric effluvia, and a variety of other substances. From these sources are derived many of the impurities which have been discovered in all atmospherical water, which must vary according to the nature of the substances, the climate, the season of the year, the direction of the winds, and many other unknown causes.

After all, we must be contented with but an impure mixture for our beverage, and yet even this may often be more serviceable to our healths than those deemed purer. Experience alone must determine it's useful and noxious qualities; such water is in general to be preferred that sits light upon the stomach, that is of a fresh, lively, agreeable taste, that boils readily, and boils garden stuff, and particularly peas and pulse quickest, and which mixes perfectly and readily with soap without curdling.

Water is purified by distillation. As it is of importance on many occasions to have very pure water, it will be necessary to point out to you the means by which it may be thus purified. The operation is performed in a vessel called an alembic; the alembic consists of two pieces, a boiler or cucurbit, and a covering called a capital or head.

The water is put into the cucurbit, from which it is raised in vapour by means of fire, and these vapours are condensed by cooling the head with cold water. The vapours thus condensed flow
into

into a vessel designed to receive them. This is called distilled water; and is purified so far as it leaves behind it in the cucurbit the salts and other fixed principles which alter it's purity. The distillation is more speedy and quick in proportion as the pressure of the air is less upon the surface of the stagnant fluid.

A true distillation is carried on every where at the surface of our globe. The heat of the sun raises water in the form of vapours, these remain a certain time in the atmosphere, and afterwards fall in the form of dew by simple refrigeration. This rise and fall of water washes and purges the atmosphere of all those particles, which by their corruption or developement might render it infectious. It is perhaps this combination of water with various miasmata, which renders the evening dew unwholesome.

OF THE ORIGIN OF SPRINGS AND RIVERS.

The quantity of water raised in vapour from the ocean, has rather extravagantly been thought by some to be equal to that which is poured into the ocean by all the rivers upon earth; and they therefore suppose, that what the sea gets by the rivers, it loses by evaporation, and that thus a mutual and equable interchange is preserved; that all the rivers are supplied with water by the vapours that are raised from the sea, carried thence by the wind, condensed against the sides of mountains, where trickling down through the crannies of the rocks, they enter the hollow places thereof, and form collections of water, from whence they issue out at the first orifice they can find, and by this means constitute springs and rivers.

There is another theory to account for springs and rivers, which refers this cause to a great abyss

of waters, occupying the central parts of our globe. It asserts, that all the phenomena of springs are chiefly derived from the vapours, veins, and issues of this great abyss, into which they are all returned; and that a perpetual circulation and equality is kept up, the springs never failing, and the sea by reason of it's communication with the subterranean waters never overflowing.

From the earliest ages these phenomena have engaged the attention of every inquisitive mind. "The sun ariseth," says Solomon, "and the sun goeth down, and pants for the place from whence he arose. All things are filled with labour, and man cannot utter it. All rivers run into the sea, yet the sea is not full. Unto the place whence the rivers come, thither they return again. The eye is not satisfied with seeing, nor the ear with hearing." At so early a period was curiosity employed in observing these great circulations of nature. The inquiry whence rivers are produced, whence they derive those unceasing flows of water, which are continually enriching the world with fertility and verdure, has been variously considered, and divided the opinions of mankind.* But as the two above-mentioned theories are those which generally prevail, and to which most others may be reduced, we shall only examine their merits.

"It seems almost unkind to disenchant the beauties of the prospect, which the first of the two foregoing theories presents to our minds. A romantic imagination can form nothing more striking than this unceasing rotation of waters; clouds arising from the ocean, travelling till they dash against the tops of the highest mountains, then descending feebly in little streams down their sides, entering the subterranean caverns of the earth, bursting forth

* Goldsmith's Hist. of the Earth, vol. i. p. 134.

forth into springs, and at last assembling into rivers, which carry the united torrent again to its parent ocean." This is amusing speculation, but alas! it is but speculation, and is so pressed with difficulties, that a more perfect theory is highly desirable.

Calculation has been pressed to favour this system, and so great a quantity of evaporated water contrived to support it, that if it fell, would drown instead of refreshing our earth.

That the rain and vapour which fall upon the earth are inadequate to the solution of the phenomena, and cannot possibly account for the origin of springs and rivers, will be made evident to you from a variety of considerations. Mons. Gualtieri, by comparing the rivers of a country with the rains that fall upon it, has shewn that after making more allowances than are reasonable in favour of the evaporating hypothesis, they exceed the rain in quantity: he has also shewn, that it is utterly impossible for the rain-water to keep up the continual course of rivers and springs. The waters discharged by the rivers of Italy into the sea, are to the rain which falls upon the land, as 55 to 27, that is, more than twice the quantity.

The earth is constantly moistened to a greater depth than the rain of the year will account for. Mr. De la Hire brought this hypothesis to the test of experiment, by examining the most essential article thereof, namely, the depth that rain and snow-water did really descend into the earth. To know this, he dug a hole in the lower terrace of the observatory at Paris, and placed therein, eight feet under ground, a large leaden basin, a little inclined towards one of its angles, to which was soldered a pipe 12 feet long, which, after a considerable descent, reached into an adjoining cellar. After having covered the head of the pipe with several flints

of different sizes, to prevent the orifice from being stopped, he threw in a quantity of earth to the depth of eight feet; the earth was of a nature between sand and loam, and thus easily permeable by water. He judged, that if rain or snow-water penetrated the earth to the depth that some springs are found at, (which in digging wells and mines are discovered to be at all depths from 8 to 800 feet,) or till they meet with the first clayey or compact stratum to stop them; that if this were the case there would soon be a spring bursting forth through the leaden pipe into the cellar. But on the contrary, after having kept the bason in this situation for no less than *fifteen years*, and the ground all the while exposed *openly* to all the rains, snow, or vapours that might fall, yet he could not observe that a single drop of water had ever passed through the leaden pipe into the cellar.

At the same time that Mr. De la Hire commenced the above described experiment, he placed another bason about eight inches under ground, and chose a place where the rain and vapours might fall, and yet the ground be screened from the heat of the sun and the action of the wind; taking care to pull up the grass and herbs that grew over the bason, that all the water which should fall on the ground might pass uninterrupted to the bottom of the bason, wherein there was a little hole with a tube to convey the water to another vessel. In eight months, that is, from the 12th of June to the 19th of February following, *no* water came by the tube, and though it *began to run* on the 19th of February, this was entirely owing to the great quantity of snow which had fallen, and was then melting. From that time the earth in the bason was always very moist, though the water would only run a few hours after raining, and it ceased running when the quantity falling was drained off.

A year

A year after he repeated the same experiment, but buried the basin *sixteen inches* under ground, taking care that there was no grass on the ground, and that it might be screened from the sun and wind; the effect was much the same as before, excepting that when a considerable time passed without raining, the earth would grow a little dry, so that a moderate rain coming on it would *not* moisten it sufficiently to make it run.

The consumption of moisture by vegetables, and the fruits, is much greater than has been commonly supposed, or generally allowed for; so great, that all the rain that falls is not sufficient to supply them with the quantity equal to what their growth demands. Mr. de la Hire planted herbs on the ground over the basin mentioned in the last experiment, and found that when these were grown up a little, the ground was so far from sending any water after rain, that *all that fell was not sufficient to sustain them*, but that they would droop and wither unless resprinkled from time to time with water. Dr. Hales found, that a plant in $21\frac{1}{4}$ days drew off all the water of the earth on which it grew, so that without a farther supply from beneath it would perish after that period; and yet he has made no allowance for what the earth in question perspired at the same time in vapour. These considerations, which might be supported by many more, abundantly prove, not only that rain-water scarcely penetrates so far as two feet, but that the quantity which falls is not sufficient to furnish what is requisite for the growth of vegetables; so that we must call in some foreign assistance for their support.

There are springs, and those common every where, so equal and constant in yielding their water at all seasons, and which are neither affected by rains nor droughts, that we cannot suppose them to be dependent on these for causes. The Reverend

Mr. Derham * describes one such under his own inspection, which was by no means consistent with the hypothesis of rain and vapour.

There are springs also too near the summits of the highest grounds in the country to derive themselves by descent from the water which falls on the surface of the ground, there being no declivity adequate to the purpose.

The evaporation from the sea being condensed by high mountains, and soaked in there, is by no means sufficient for the production of springs and rivers; † for whatever effect this vapour may seem to have in southern climates, and in islands placed in the middle of the ocean, it cannot fairly be applied to the springs of inland countries and northern climates. Nor have the advocates for this hypothesis considered, that where the evaporation of the day is so copious, the dews of the night which fall again on the same surface (sea or land) are nearly in the same proportion; so that much less has been gained in this way than has been generally supposed. Dr. Derham shews also, that springs occur in great plenty, and are constant in their course, even in times of the greatest drought, where the country is in general very low, and there are no mountain tops to condense the vapours.

The vapours and rain fall also upon the sea as well as upon the land; and the surface of the ocean is considered to be as large again as that of the dry land: so that we may justly suppose, that two thirds of whatever is raised in vapours returns from whence it came without falling upon the dry land.

No one will deny that rain and melted snow will produce many temporary springs, and increase the

* Philof. Transf. No. 289, and 315.

† Memoirs of Literature, Aug. 1725. Jones's Physiological Disquisitions, p. 499. Catcott on the Deluge, p. 174.

the discharge of rivers; but this is a partial consideration, and by no means adequate to that constant supply, and to that vast quantity of waters which are to be accounted for, and which are constantly in action.

I shall, therefore, now consider the subterraneous store,* and the vapours that arise from them. And here it is a well known fact, that we never fail to find water when we penetrate deep enough into the bowels of the earth; and the deeper we go, the waters occur in greater plenty. This does not look as if their stores depended upon any accident at the surface, for then they would rather be diminished and fail us when we work lower, their supplies being extended according to this account in springs and rivers upon the surface: but the contrary is always the case; therefore the sources are not above, but below. This conclusion seems too obvious to be avoided. In sinking mines it is very common to break in upon veins, and sometimes large and powerful courses of water in incredible quantities, which either overflow the works, or require continual assistance to drain them.

When the earth is cut through, it yields water, as naturally as the body, which abounds with vessels, yields blood when it is wounded. The deeper the wound the greater is the effusion of blood, because the largest channels lie deep, and the largest of all which feed the rest, are placed in the central parts of the body. Thus it is with the body of the earth, the effusions of water observable near the surface have their supply from reservoirs which lie deeper, and they in their turns are fed by larger and deeper, till we come to the grand repository

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of

* Those who wish to see strong evidence in favour of these subterraneous stores, should consult Calcott on the Deluge, and Jones's Disquisitions, p. 525.

of all, which keeps up a general communication between the waters of the land and those of the sea.

Those who have been eye-witnesses of what passes within the earth, have been generally of opinion, that steam and vapour is in continual action there, though more at some times than at others; that there is frequently a very sensible warmth at the greatest depths, and many tokens of moisture arising upwards from the lower parts. Scheuchzer, who was very conversant in these researches, says, "*firmiter persuasus sum, copiosissimus ex imis montis visceribus ad cacumen sublevari caloris subterranei ope vapores aqueos.*" Now as the waters of the sea are salt, while the spring waters of the land are fresh, and consequently lighter, a column of sea water will be a counterpoise to an higher column of fresh water. If therefore the waters of deep seas have any communication with the land, and their weight has due effect, water may rise to any required height upon statical principles, either by running channels, or by sap and percolation; for water underneath a mass of dry sand will be soaked upwards to its surface.* Sir Isaac Newton tried this experiment on a tube filled with dry ashes, and found the water ascend through them with ease. In the rocky caverns of mountains much may be effected by the slow ascent of steam, which will be condensed as it comes near to the air, and distil downwards through those cracks and chasms where it finds an outlet.

When we dig for springs in small islands, and lands lying near the sea coasts, it is common to find veins of brackish water; these are certainly derived from the sea. The water that is more remote,

* Since this work went to the press, a machine has been published for purifying water by ascent. The contrivance is Mr. Peacock's.

mote, and at a greater elevation from the sea, becomes fresh by degrees; therefore it sweetens in it's progress by percolation. Here the process is palpable. But the earth being full of open veins and fissures, and strata of loose and permeable matter, must have a communication with the sea to great distances; and where the distance is so great that the lateral supply cannot take place, those deeper communications, of which there are so many evidences, will never fail us; and where percolation cannot reach, the subterraneous vapours, which are always circulating, must have their effect.

In short, wherever you dig beneath the surface of the earth, except in very few instances, water is to be found, and it is probable that by this subterraneous water springs and rivers, nay a great part of vegetation itself, are supported. It is this subterraneous water raised into steam by the internal heat of the earth that feeds plants. It is this subterraneous water that distills through it's interstices, and there cooling, forms fountains. It is this that by the addition of rains is increased into rivers, and pours plenty over the whole earth.

This reasoning may be illustrated by a pleasing apparatus, which is sold in our streets by the itinerant Italians. The tube is about three feet high, and is fixed to a board, the tube near the top is globular, and will hold a large quantity of water, from whence it is continued of a less size to the bottom, where it is curved upwards, and annexed to another globe, from whence proceeds upwards another smaller tube, bent in an irregular meandering manner to the top, where it is curved as you see downwards, and is joined to the upper globe. In the inside of the lower globe, one part of the tube is so contracted as to form a fit passage for a spring, or jet d'eau, to arise from it. I pour coloured water into the tube by means of this aperture,

ture, letting it rise therein till it has filled the upper globe; the air in the lower globe will be condensed by the pressure of the water endeavouring to rise to it's level, the reaction and spring of the air will impel the water you see upwards through the small tube and all it's meanders, and make it fall into the upper globe, and thus cause a constant circulation as long as any water remains in the upper globe. Now if you suppose the upper globe to represent the sea, the lower globe to represent the abyss, and the jet d'eau to be a spring breaking out therefrom into the hollow parts of the earth, and from thence continued through small winding fissures to the surface, and from the channels of the river into the sea again, the one may be allowed to be a proper representation of the other, and an experimental illustration of the possibility of such a circulation.

OF THE SALTNESS OF THE SEA.

No sooner have we endeavoured to discuss one question, than another presents itself for our consideration, one for which philosophy has not yet found a satisfactory solution. To discover the primary cause of that peculiar bitterish saltness which characterizes sea-water, has exercised the naturalists of all ages; and Father Kircher long since observed, that the fluctuations of the ocean were scarcely more various than the opinions of men concerning it's saline impregnation. Dr. Halley,* who often endeavoured by weak speculations to lessen the authority of the Bible, thought he had hit upon a principle, which would discover the cause of the saltness of the sea, and carry us back almost with demonstration to the true date of the creation.

* Phil. Transf. No. 344. Watson's Chemistry, vol. ii. p. 93. Jones's Disquisitions, p. 524.

creation. He laid it down as a principle, that the water of the sea derives all it's saltness from the land, that a small portion of salt is continually washed down from the land by rivers, and carried into the sea, which has gradually acquired it's present quantity of salt from the long continued influx of rivers. The water which is thus carried into the sea by the rivers, is again separated from it by evaporation, nothing but fresh water rises from the sea in vapours, the saltness remains behind. The salt thus carried into the sea must for ever remain there, it must therefore be a perpetually increasing quantity, and the sea must every year become more and more salt. If therefore, says the doctor, the increment of salt could be found for any given term of years or ages, we should then be able to work backwards by the rule of proportion, and discover the time when the sea first began to grow salt; that is, when the world began to exist. It is rather mortifying for infidelity, that the problem requires ages for it's solution. The idea of *salting* the sea with *fresh* water, is also rather uncommon, but worthy of a sceptical philosopher. The reasoning is defective in many points. For allowing that the sea evaporates into fresh water, and that thus the salt it contains is left behind, yet we are still no nearer than before, unless while the sea is losing fresh water by evaporation, you could stop all the rivers, so that no fresh water might be added in the mean time. For Dr. Halley maintained, as you saw before, that as much fresh water is carried to the sea by the rivers as it loses by evaporation, that the rivers therefore will all be running on, and bringing in fresh water, while the vapour is rising from the surface; thus you see when things are compared together, the argument will end in a cypher.

The postulatam, on which the argument is built,

built, is itself erroneous, as it supposes the water of the ocean was fresh at the beginning of the world; and the whole inquiry seems to be after the cause of a phenomenon which has probably no secondary cause at all.* The supposition that the water of the ocean was originally fresh, is an opinion concerning a matter of fact, which can never be proved either way; and it is surely extending speculation too far, when we attempt to explain a phenomenon coeval with the formation of the earth. The saltness of the sea is as necessary to the constitution of that element, and to the well-being of the terraqueous globe, as the redness of the blood is necessary to the improvement of the serum in the animal system. The sea is no more salt by chance, than the blood is red by chance. It is a wise provision of the CREATOR, that the immense body of water which occupies more than two thirds of the globe should be thus salted and seasoned for its own preservation, and for the salubrity of the atmosphere; on which account the ocean is saltier under the torrid zone, where the heats are more productive of putrifaction, and the saltness decreases as we approach the pole, all indicating design, and if it be true that the agitation and ventilation of the sea is not sufficient in vast tracts and deep waters to keep it sweet without a due proportion of salt, Dr. Halley's scheme would have poisoned the world.

The degree of saltness in the sea varies in the same place at different seasons, sometimes at different depths.

Dr. Watson informs us, that from some experiments made in a voyage from England to Bombay, in the East Indies, that the weight of seawater was the greatest, not precisely at the equator, but where the sun was vertical, and where in similar circumstances the heat was greatest; and that

* See Watson's Chemistry. Jone's Physiological Disquisitions,

the weights of equal bulks of Thames-water, of sea-water at Teneriffe, and at St. Jago, were 659, 673 $\frac{1}{2}$, 780 $\frac{1}{2}$ grains, the proportion of which number may be expressed thus: Thames water 1000, Teneriffe sea-water 1022, St. Jago sea-water 1184. In general, sea-water possesses about $\frac{1}{12}$ or $\frac{1}{16}$ of it's weight in salt. He also mentions the following simple method for estimating the quantity of salt in sea-water; a method so simple that every common sailor may understand and practise it. Take a clean towel, or any other clean cloth, dry it well in the sun or before a fire, then weigh it accurately, and note down it's weight, dip it in sea-water, and when taken out wring it a little till it will not drip; weigh it in this wet state, then dry it, and when it is perfectly dried, weigh it again; the excess of the weight of the wetted cloth above it's original weight is the weight of the sea-water imbibed by the cloth; and the excess of the weight of the cloth after being dried above it's original weight is the weight of the salt retained by the cloth; and by comparing this weight with the weight of sea-water imbibed by the cloth, you obtain the proportion of salt water contained in that species of sea-water.

Congealed sea-water will, when thawed, yield fresh water. To prove this, some sea-water was taken up off the North Foreland; it was exposed to a freezing atmosphere, and it afforded an ice perfectly free from any taste of salt. The specific gravity of the water produced from the melting of the ice was somewhat greater than that of distilled rain-water, and somewhat less than a mixture of rain and snow-water taken out of a water-tub. The degree of cold at which the sea-water froze was 28 $\frac{1}{2}$ of Fahrenheit's thermometer, or 3 $\frac{1}{2}$ lower than that in which common water freezes. This difference will vary according to the quantity of salt
salt

salt contained in the water. The freezing of sea-water was formerly practised, and is probably still so in the northern parts of Europe, with a view to lessen the expence and trouble of extracting salt from sea-water.

A variety of attempts have been made in our own and other countries to procure fresh from sea-water: the means used for this purpose is distillation, and the most approved methods are those of Dr. Irving, and Mr. Poissonier. To give you an idea of this method, suppose a tea-kettle to be made without a spout, and with a hole in the lid in the place of the knob; then the kettle being filled with sea-water, the fresh vapour which arises from the sea-water as it boils, will issue out through the hole in the lid; into that hole fit the mouth of a tobacco-pipe, letting the stem have a little inclination downwards; then will the vapour of fresh water take it's course through the stem of the tube, and may be collected by fitting a proper vessel to it's end: this will give you a general though imperfect idea of an apparatus for this useful purpose,

I have already mentioned to you the dissolving power of water, and, in one of the preceding Lectures, given you such reasons as will probably induce you to think that this power is chiefly to be attributed to it's combination with, and the presence of fire acting in it. Salts are the substances which it dissolves the soonest, and in the greatest quantity; it will not dissolve equal quantities of all kinds of salts, some being more soluble therein than others; all salts are more speedily dissolved in warm than in cold water. When water is saturated with any kind of salt in a definite degree of heat, it will retain that salt as long as it retains it's heat; but if the heat be lessened, the transparency of the solution will be destroyed, a part of the salt will become visible, and fall to the bottom; what
thus

thus falls down will be re-dissolved as soon as the water regains the fire it had lost. Thus the quantity of the salt which is precipitated from the cooling of the water, will depend partly on the degree of heat in which the solution is saturated, and partly on the degree of cold to which the solution is reduced. — Thus water of 80 degrees, when saturated with salt, contains more salt than it would do if it had only 70 degrees of heat; and in being cooled to 50 degrees, the precipitation will be greater in the first instance than in the second. Salt is much longer in being dissolved when it is in a compact state, than when it is reduced into a fine powder, because when it is in the form of powder it presents a much larger surface to the water than when it is one solid lump.

When salts are mixed with water, a considerable quantity of air is separated from the water, and the whole of the fluid appears muddy, occasioned by a number of very small bubbles, which rise to the top so as to form a scum; when all are risen, the water again becomes transparent. This phenomenon should be noticed, as many have been deceived by it, especially those who have written on mineral waters; they often speak of an effervescence in them where there really is none, and the appearance of it is nothing more than the air escaping.

The more salt you add to water, the more slowly it will be dissolved; after a certain quantity it will dissolve no more; the points at which the salts cease to dissolve is called the point of *saturation*. The proportion of water is very different with respect to different salts. Sir Isaac Newton supposed, that there was an equal distribution of salt through a determined space of water; hence their deposition in regular order. The salt often requires some time before it can be so disseminated that it's particles may be arranged at equal distances

tances throughout the whole fluid; in time, however, this is effected. Throw a heavy salt, as blue vitriol, into a glass of water, it at first sinks to the bottom, and after some days begins to impart its colour and qualities to the particles of water immediately surrounding it: as that part of the water which is in contact only acts on the salt, it is soon saturated, and being thus rendered heavier, remains round the salt as an atmosphere; the rest of the water acts on this surrounding atmosphere, therefore in a little time another stratum will be formed containing less salt than the former; innumerable horizontal strata will at length be formed containing less and less salt: hence the diffusion is very slow, unless it be assisted by agitation. The vitriolic acid is used in bleaching, being diluted in the water in which the linen is steeped. The bleachers at first thought it was enough merely to throw the acid into the water; this, however, always corroded some of the linen, because the vitriolic acid always sinks to the bottom, and remains there a long time before it is regularly disseminated. When mixed thoroughly by agitation, the salt will never separate again.

There is another phenomenon attending the solution of salts, namely, the production of cold; this we have already explained to you, and shewn that it depends on the quantity of fire absorbed to maintain and keep up the fluidity of the salt.

LECTURE XIII.

OF WATER IN THE STATE OF ICE.

I HAVE shewn you, that water is in a fluid state only on account of it's combination with fire; that if it loses the fire, which is thus combined with it, it's particles cohere together, and form a hard substance called ice.

Water in freezing parts with the fire, with which it was combined. If a thermometer be immersed in a vessel of freezing water, the mercury will rise some degrees above 32° , while another thermometer, in the open air, will remain fixed at or some degrees below that point; part of the fire which was fixed in the water being disengaged, escapes into the air when it assumes a solid form. A similar disengagement of fire is perceived in the crystallization of salts. On the other hand, when ice melts, it combines itself with a considerable quantity of fire, which at the same time does not increase the temperature, which you may prove by this experiment. Let there be a pound of ice at 32° , mix a pound of water at 172 therewith, and, in a few moments, the ice will be melted, and the temperature of the mixture will be 32° ; a quantity of fire, which raised the thermometer 140° ($140 + 32 = 172$), was absorbed by and combined with the ice to give it a fluid form; but the fire, thus absorbed, does not produce any effect upon the thermometer.

The fire, which the water absorbs, when it acquires a fluid form, is again separated from it by congelation; for if a pound of water at 32° be mixed with an equal quantity of ice at 4° , nearly $\frac{1}{2}$ of the water will be frozen, and the temperature of the mixture will be 32 . Now, in this experi-

ment, the ice is raised from 4° to the freezing point, that is, 28° . It is therefore plain, that by the congelation of $\frac{1}{4}$ of a pound of water, a sufficient quantity of fire is evolved to raise a pound of ice 28 degrees: now five times 28 is 140° , so that the fire, which is extricated by congelation, is precisely equal to that which is absorbed by the melting ice. Messrs. Lavoisier and de la Place have given us this general idea of this phenomenon. *The heat, necessary to melt ice, is equal to three-fourths of that which would elevate the same weight of water, at the freezing point, to that of boiling water.*

The external air promotes the formation of ice; water in a close vessel freezes very slowly; but if exposed to air of the same temperature, ice will very soon be formed. A similar phenomenon is said to be observed in the crystallization of salts; many saline solutions, which will remain in that state in close vessels, display crystals almost as soon as you open the mouth of the vessel, and expose them to the contact of the atmosphere.

Gentle motion, or a slight agitation of the fluid, facilitates its conversion into ice: nearly in the same manner, some saline solutions are determined to crystallization by a slight agitation. It is probable, that the two above-mentioned circumstances facilitate the separation of the combined fire from the water.

Boiled water may be brought a greater number of degrees below the freezing point without congealing, than unboiled water, which contains more air.

Substances, which lessen the transparency of water, render it at the same time more difficult to be cooled below 32° without freezing, and dispose it to shoot more readily into ice.

Foreign substances chemically combined, or dissolved

dissolved in water, do not take away it's property of being cooled, though they alter the degree at which that property commences.

Striking the bottom of a tumbler with cooled water against a board, will produce instant congelation; when stirring the water, or shaking it in the hand, will have no effect. The most certain method of bringing on congelation is, that of rubbing a bit of wax on the side of the tumbler, but under the water; a particular roughness in the motion is felt, and a crust of ice is immediately perceived under the wax upon the glafs.

These methods succeed best in proportion as the water is more cooled below the freezing point; unless the cooling amounts to 4 or 5 degrees, the friction from the wax is often in vain.

When water is cooled below the freezing point, the contact of the least particle of ice will make it instantly congeal; the glacial crystals shooting all through the liquor, from the spot where the ice touches, till the whole comes up to the freezing point. Few experiments of the minute kind afford a more striking spectacle than this, especially when the water has been cooled, nearly as much as possible, below the freezing point; both from the beautiful manner in which the crystals shoot through it, and the rapidity with which the mercury in the thermometer immersed in it, runs through a space of 10 or 11 degrees, stopping and fixing always at 32 in pure water.

The effect of ice, in hastening congelation, explains some phenomena. In a calm day, when the temperature of the air was about 20°, two vessels, with distilled water, were exposed to the cold; one of them was slightly covered with paper, the other was left open; the former bore to be cooled many degrees below the freezing point, whilst a crust of ice always formed on the surface

of the other, before the thermometer immersed in the middle of it, came to the freezing point; most probably arising from the frozen particles, which, in frosty weather, are generally floating in the air.

Oil spread over the surface of water has been found to prevent it from freezing, when other water similarly exposed, has had a crust of ice upon it; the oil preventing the frozen particles from coming in contact with the water. In frigorific mixtures the congelation is often brought on by raising the immersed thermometer a little out of the water, and lowering it again, some of the adhering water having frozen on the stem.

To insure the greatest degree of cold in water without freezing, you must cool it in a very gradual manner, keeping the cold of the frigorific mixture regularly, only two or three degrees below that of the water. Sudden cooling may be considered as one of the causes which hasten congelation. Metallic or too thin vessels are not proper for these experiments, as they transmit fire too readily. The frigorific mixture should be kept a little below the edge of the water in the tumbler, otherwise the congelation quickly begins at that place.

Fahrenheit cooled water 15 degrees below its common freezing point without freezing; Mr. de Luc to 14°. It is not improbable, that if water could be thoroughly purged of air, it might be cooled 18° below the freezing point without congelation. Other fluids will bear to be cooled much more below their proper point of congelation.

When water is nearly congealed, it augments in bulk, as we shall shew you by this simple experiment. I shall take this tube filled to E, and plunge the bulk thereof in the mixture of salt and ice; you will observe that the water at first rises in the tube, on account of the sudden contraction of the

the bulb on being immersed in this cold medium; the water now contracted in it's turn falls again, and will remain for some time at the same point; in a little time it will begin to expand; it has now risen to H, and soon will rise with some violence much higher; it is now got to I; the water in the bulb you see loses it's transparency, and grows cloudy, and is freezing during the congelation; and while the ice is hardening, the water rises in the tube; it now runs over it.

This expansive force of ice is very great, as you will be convinced, by the detail of a few interesting experiments. The Rev. Mr. Jones made a long cylindrical metal box with a strong rim; to this he applied a cover, fitting them with great exactness by grinding them one upon the other in a turning-lathe. He then prepared some water, first by boiling, and secondly by exhausting the air from it, which was so far effected, that when cold it did not yield the least bubble of air, on trying it by the air-pump. He filled the box with water, till it stood convex above the rim; and having applied a wet leather to the cover, he screwed it down firmly upon the box with four iron screws. In this state, it is probable, the box could not have been separated from it's cover by a weight less than half a ton. He plunged the whole into a freezing mixture, in less than half an hour the water was froze into a solid mass, and as it's bulk increased, the three screws were forced by the violence of the pressure, and the cover was raised up on one side a quarter of an inch above the rim.

To measure this force with more exactness, the same gentleman made another experiment, using the same box, and filling it as before with water purged of it's air, and being covered, but not screwed down; it was placed upon an oaken pedestal, which had for it's base a flat hewn stone

of about a foot square. The shorter arm of a very strong lever was made to press upon the cover; this lever was compounded with two more to increase the power; at the extremity of the longest arm of the most remote lever a cord was fastened, which ran over a pulley, and had a weight of 28lb.; by all these combined, the cover of the box was pressed with a force of above 2296lb.; while it was so pressed down, the water within it was froze, and the agent by which the water was congealed overcame the whole force of the machine. The experiment, however, was not complete; for when the water began to freeze, and the cover of the box to be raised from the rim, the ground yielded under the pressure, and the flat stone, which served as a base to the pedestal, sunk a little below its first position; by this means the force was at first spent upon the ground, and did not take place in the machine till the ground would give way no more. It was, however, so sensibly perceived in the machine, as to prove that it was at least superior to *one ton two hundred and ninety-six pounds*. The box contained $5 \frac{5}{8}$ cubic inches. May not this force proceed from fire, not as giving, but as restoring an equilibrium, which has been interrupted? For light and fire may have powerful effects in nature, where they give no sensible heat.

By the expansive force of ice, Huyghens burst an iron tube of half an inch in thickness. In the experiments of the academy del cemento, bombshells and the strongest vessels being filled with water, were burst in pieces by the fluid on its congelation.

When water is congealed into ice, a great number of bubbles are produced and imprisoned in it; as these bubbles are produced in the act of freezing, they extend the bulk of its water, and render the ice specifically lighter, and capable of floating

floating thereon. That these bubbles are, in a great measure, the causes of this expansion, is clear from the experiments of Marriotte and Mairan, who found ice made with water, well purged of air, sensibly heavier than that formed from the same quantity of common water. According to Mairan, ice formed of water, purged of air, exceeded $\frac{1}{2}$ in bulk the volume of water which formed it; while ice made from water, not purged of air, exceeds the water $\frac{1}{4}$ or $\frac{1}{10}$ in bulk; therefore floats with about one tenth part of it's thickness out of, or above the water that bears it. From hence you may infer the amazing thickness of the ice in the northern seas, where the portion above the surface is higher than the masts of the tallest vessels.

When a tract of ice in strong masses is spread over the ground, and other ice continues to be formed underneath, where there is not room for it's expansion, as in the glaciers of Switzerland, the ice underneath sometimes expands with such force as to rend the superior strata with violent explosions. In the frosty climates of the polar regions, these explosions are frequent, and sometimes as loud as a cannon.

The expansive force of ice is applied on several occasions to save the labour of man, and perform such things as are beyond the reach of art. Blocks of slate-stone, which is formed in thin plates or strata, not separable by a tool, are taken out of the quarry and exposed to rain, which soaking into the pores of the stone is there frozen into ice, which, by it's expansion, breaks the stone into thin plates. In the iron works, they sometimes, in order to break an old bomb-shell, fill it with water, then fasten up the vent and expose it to the frost, which bursts it into pieces without farther trouble. If you expect, therefore, that any liquor

will freeze, and wish to preserve your vessel, leave room therein sufficient for this accidental extension.

The effects of this expansion are observable in a thousand phenomena. Trees are burst, rocks are rent; walnut, ash, and oak-trees, are sometimes cleft asunder, and this with a noise like the explosion of fire-arms.

Nor are the effects of extreme cold less wonderful; metallic substances will then blister the skin like red-hot iron; the air, when drawn in, hurts the lungs, and excites coughing.

When the French mathematicians wintered at Tornea, in Lapland, the external air, when suddenly admitted into their rooms, converted the moisture of the air into whirls of snow. Their breast seemed to be rent when they breathed it, and the contact of it was intolerable to their bodies; and the aqueous parts of spirit of wine, which had not been highly rectified, burst some of their thermometers.

Extreme cold often proves fatal to animal life; 7000 Swedes perished at once in attempting to pass the mountains, which divide Norway from Sweden. In cases of extreme cold, the person attacked first feels himself extremely chill and uneasy, he begins to turn listless, is unwilling to walk or use the exercise necessary to keep him warm, and at last turns drowsy, sits down to refresh himself with sleep; but wakes no more. An instance of this was seen at Terra del Fuego, where *Dr. Solander*, with some others, having taken an excursion up the country, the cold was so intense as to kill one of their company. The doctor himself, though he had warned his companions of the danger of sleeping in that situation, yet could not be prevented from making that dangerous experiment himself; and though he was awaked with
all

all possible expedition, his body was so much shrunk in bulk, that his shoes fell off his feet, and it was with the utmost difficulty he was recovered.

In those parts of the world, where vast masses of ice are procured, the accumulation thereof by absorbing the fire from the atmosphere, occasions great *sterility* in the neighbouring countries, as is particularly the case with the islands of Iceland, Greenland, Statenland, &c.

Ice is subject to a constant diminution of it's weight when exposed to the common air. Mr. Boyle exposed two ounces of ice to a sharply freezing air a little before midnight, and found it in the morning diminished 10 grains in weight. In long continued frosts, the ice formed in ponds, and other small collections of water, is sensibly diminished every day, and often wholly evaporated; and a fall of snow may be seen considerably wasted in a few days in the severest season. The principal cause of this loss of weight seems to be the incessant action and abrasion of the air upon the surface of the ice.

Notwithstanding this loss of weight to which both ice and snow are subject in the *coldest* weather, and the thaw which they experience in the hottest, some have doubted, whether the quantity of congealed water be not an increasing quantity. A philosopher,* well acquainted with the nature of the Alps, expresses himself upon the subject in the following manner: "One cannot doubt concerning the increase of all the glaciers of the Alps; *their very existence* is a proof, that in preceding ages, the quantity of snow which has fallen during the winter, has exceeded the quantity melted during the summer. Now, not only the same cause still subsists; but the cold, occasioned by the mass of ice already formed, ought to augment it still

* Mr. De Luc.

still farther, and thence more snow ought to fall, and a less quantity of it be melted."

Though this be admitted, it by no means follows that there is an annually increasing quantity; for, besides the heat of the air in summer, there is another cause, which tends to prevent any indefinite augmentation of congealed water,—*the internal heat of the earth*. The general heat of the springs of water, situated deep in the bowels of the earth, is 48 degrees. In mountainous countries it may be somewhat less, but sufficient notwithstanding for the purpose here mentioned. When the snow, incumbent on any spot of ground, is but thin, it may so far cool the earth, that the internal heat may not be able to dissolve it; but when the bed is *thick* enough to protect the earth from the influence of the atmospherical cold, that surface of the earth may, even in the coldest winters, receive more heat from the earth, than cold from the atmosphere, and be therefore dissolved at all seasons of the year. *

This reason is corroborated by fact; for it is said, that streams of water issue from the bottom of the *glaciers* in the *Alps*, in the greatest severity of winter; so that whether the internal heat of the earth be admitted or not, as a cause sufficient to explain the phenomenon, a constant thaw of the ice or snow, which is contiguous to the surface of the earth in the *Alps*, cannot be denied; and this, added to other causes, may render it probable, that the quantity of congealed water has it's limit, even in the coldest country.

Ice appears to be a kind of confused crystallization. Mr. De Mairan observed, that the needle-formed crystals of ice unite in an angle of 60 or 120°. If a piece of ice, which contains water in it's internal part, be broken, the water runs

* Watson's Chemistry, vol. iii. p. 184.

runs out, and the internal cavity is found to be lined with beautiful tetrahedral prisms. These prisms are often articulated and crossed. When it snows at Moscow, and the atmosphere is not too dry, the air is observed to be loaded with beautiful crystallizations regularly flattened, and as thin as a leaf of paper. They consist of an union of fibres which shoot from the same center to form six principal rays; these rays divide themselves into extremely small blades. Mr. Macquart has observed several of these flattened radii, which were ten lines in diameter.

Hail and snow are modifications of ice. Hail is probably produced by a sudden disengagement of the fire by which water is rendered liquid, and is generally accompanied by thunder. *Hail, snow, and ice*, are wonderful images of the great operations in nature; and if your senses had not acquainted you how these things are created out of something, and are themselves only the properties of fire, air, and water, brought out of a prior state into such a compaction and creation as is called snow, hail, and ice, philosophy would have left you as ignorant of their nature, as it is of most material substances. Mr. Chaptal relates the following curious observation, made by himself at Montpellier, Oct. 29, 1786. "On that day four inches of water fell at Montpellier, a violent explosion of thunder was heard about four in the afternoon, which appeared to be very near, and was accompanied by a most violent shower of hail. At this instant, a druggist, who was employed in preventing the mischief occasioned by the filtration of water through the wall, was greatly astonished by perceiving the water that came through the wall instantly changed into ice. He called in several of his neighbours to partake of his surprize. Mr. Chaptal visited the place about a quarter of an hour afterwards, and found

5

about

about ten pounds of ice at the foot of the wall: he was well assured it could not have passed through the wall, which did not exhibit any crack. Did the same cause which determined the formation of hail in the atmosphere, act equally in the cellar?"

A mass of ice formed by a slow congelation, appears very homogeneous, and sufficiently transparent for a small distance from the surface first frozen; but in the interior parts, and particularly towards the middle, there is a considerable number of bubbles of air. A quick congelation spreads these bubbles indifferently through the whole mass, which becomes therefore almost opaque, being composed of small parts of different densities; and the upper surface is more rough and irregular than when the congelation has been slow and gradual.

The ice of running waters is differently formed from that of standing waters; in these the surface is first froze, and thickens gradually by freezing one stratum of water after another; and it is carried on much more expeditiously than when it is in motion.

When the cold is sufficient, the water freezes on the edges of a river. The ice thus formed is, however, often broken and carried away by the current; more ice is then formed, which is again broken off, and so on. The cakes of ice thus formed, are at first very thin, and easily broken by the first shock, so that very few remain whole, but are broken in a thousand pieces. Thus in a little time the river is covered with small pieces of ice (that the least obstacle stops) floating down its stream. These by degrees, and from a variety of circumstances accumulate in size and number; and the ice thus formed is very irregular and opaque, and mixed with a variety of small heterogeneous substances, as bits of straw, herbs, &c. which had attached themselves to the pieces of ice. By a

continual increase in size by the various obstacles to be met with in the course of a river, such as bridges, &c. these cakes are at last so joined as to cover the river. In very severe frosts, and very cold climates, rivers have been known to be froze over with great rapidity. Dr. Goldsmith mentions having seen the Rhine frozen at one of it's most precipitate cataracts, and the ice standing in glassy columns like a forest of large trees, the branches of which have been lopt away. So hard does the ice become in cold countries, that in 1740, a palace of ice was built at Peteriburg, after a very elegant model, and in just proportions of Augustan architecture. It was 52 feet long, and 20 feet high. The materials were quarried from the surface of the river Neva, and the whole stood glistening against the sun with a brilliancy almost equal to his own. To increase the wonder, 6 cannons of ice, and two bombs, all of the same materials, were planted before this extraordinary edifice: the cannon were three pounders, they were charged with gunpowder, and fired off; the ball of one pierced an oak plank 2 inches thick at sixty paces distance, nor did the piece burst with the explosion.

In the northern parts of the world solid bodies are liable to be hurt by the frost. Timber is often apparently frozen, and exceedingly difficult to be sawed. Marble, chalk, and other less solid terrestrial concretions, are often shattered by long and durable frosts. Metals are contracted by frost: thus an iron tube 12 feet long, upon being exposed to the air in a frosty night, lost two lines of it's length. The expansion of water I have already mentioned to you. Trees are often destroyed by frost, and appear as if burnt by the most excessive heat.

Frost generally proceeds from the upper parts of a body downwards; but how deep it will reach in the earth is not easily known, as this depth will
vary

vary from a variety of causes, as the duration of the frost, the texture of the ground, &c. After a hard frost of some days, Mr. Boyle dug in an orchard where the ground was level and bare, and found the frost had scarce reached 3 inches and a half below the surface. Nine or ten successive frosty nights froze the ground in the orchard only to the depth of 8 inches and a half. In a garden at Moscow, the frost in a hard season only penetrated 2 feet. Water, like the earth, seems not disposed to receive any very intense degree of cold at a considerable depth or distance from the air; the vast masses of ice found in the northern seas being only many flakes and fragments, which, sliding under each other, are cemented together by the congelation of the intercepted water.

The great power of frost on vegetables is a thing sufficiently known; but the difference between the *frosts* of a *severe winter*, and those of spring mornings, have been but little attended to; you will, however, find it a subject very worthy of your attention.

The frosts of a *severe winter* are much more terrible than those of the *spring*, as they bring on a privation of all the products of the tenderer parts of the vegetable world; but they are not *frequent*, such winters happening but once in an age; but the frosts of the spring are more injurious, as they are repeated every year.

In regard to trees, the great difference is this, that the frosts of a severe winter affect their wood, their trunks, and the large branches; whereas those of the spring have only power to hurt the buds.

The winter frosts happen at a time when most of the trees have neither leaves, flowers, nor fruits upon them, and have their buds so hard as to be proof against slight injuries of the weather, especially if the preceding summer has not been too

wet.

wet. Hard frosts, which happen late in the winter, cause very great injuries even to those trees which they do not destroy.

It is not *the severest cold or most fixed frost that does the greatest injury to vegetables*. Though this observation is directly opposed to popular opinion, it will be found not less true, nor any way repugnant to reason. It is *humidity* that makes frost fatal to vegetables, and therefore every thing that can occasion humidity exposes them to these injuries. It is well known, that vegetables always feel the frost very desperately in low places where there are fogs. The plants which stand by a river side are often destroyed by the spring and autumnal frosts; whilst those of the same species, which stand in a drier place, suffer but little, if at all. The low and wet parts of forests produce worse wood than the high and drier. The coppice wood in wet and low parts of common woods, though it push out at first more vigorously than that of other places, yet never comes to so good a growth; for the frost of the spring killing these early top shoots, obliges the lower parts of the trees to throw out lateral branches. Frost seldom hurts the late shoots of vine or flower buds, except when it follows heavy dews, or a long rainy season, and then it never fails to do great mischief.

Frost does more mischief on newly cultivated ground than in other places, because the vapours find an easier passage there than from other places. Trees newly cut suffer more than others by spring frosts, because they shoot more vigorously. Side shoots of trees are more subject to suffer from spring frosts, than those at the top; in general, the effects of the spring frosts are much greater near the ground than elsewhere.

On the same principles you may explain why the south sides of trees are more damaged by a
severe

severe frost than the north. Great damage is also done to the western side of trees and plantations, when after a rain with a west wind, the wind turns about to the north at sun-set, which is common in spring; or when the east blows upon a thick fog before sun-rising.

In the state of the atmosphere we denominate a frost, there is an intimate union between the air and the water in the air; therefore except in high latitudes, frosty weather is generally *clear*. When such an union takes place, either in winter or summer, the atmosphere is inclined to *absorb fire*, and consequently to produce frost. Thus in clear settled weather, even in summer, though the day may be excessive hot, yet the mornings and evenings are extremely cold.

The air in frosty weather, or clear dry weather, being always ready to absorb fire from every substance in contact, must of course absorb part of that contained in the vapour, which floats in it's bosom.

Though vapour is capable of becoming much colder than water without being frozen, yet by a continual absorption it must at last part with it's *latent fire*, i.e. what is essential to it's existence as vapour, and without which it is no longer vapour, but water or ice. When a frost has acquired a certain degree of intensity, then the vapours every where dispersed in the air give out their latent fire, the atmosphere becomes clouded, the frost either goes off or becomes milder, and the vapour descends in rain, hail, or snow, according to the disposition of the atmosphere.

TO MAKE ICE.

In many countries the warmth of the climate renders ice not only a desirable, but even a necessary article; so that it becomes an object of some consequence

consequence to fall upon a ready and cheap method of procuring it. Though the cheapest method hitherto discovered, seems to be that by means of sal-ammoniac or Glauber's salt; yet it may not be amiss to take notice of some attempts made by Mr. Cavallo, to discover a method of producing a sufficient degree of cold for this purpose by the *evaporation* of volatile liquors. He found, however, in the course of these experiments, that ether was incomparably superior to any other fluid in the degree of cold it produced. The price of the liquor naturally induced him to fall upon a method of using it with as little waste as possible.

The apparatus for using the least possible quantity of ether for freezing water, consists in a glass tube terminating in a capillary aperture, which is to be fixed upon the bottle containing the ether. Round the lower part of the neck some thread is wound, in order to let it fill the neck of the bottle. When the experiment is to be made, the stopper of the bottle containing the ether is to be removed, and the tube just mentioned put in it's room. The thread round the tube ought also to be previously moistened with water before it is put in the neck of the bottle, in order the more effectually to prevent the escape of the ether betwixt the neck of the phial and tube. Holding then the bottle by it's bottom, and keeping it inclined, the small stream of ether issuing out of the aperture of the tube, is directed upon the ball of the thermometer, or upon a tube containing water or other liquor that is required to be congealed. As ether is very volatile, and has the remarkable property of increasing the bulk of air, there is no aperture requisite to allow the air to enter the bottle while the liquor flows out. The heat of the hand is more than sufficient to force out the ether in a continued stream at the aperture,

In this manner, by throwing the stream of ether upon the ball of a thermometer in such a quantity, that a drop might now and then, every 10 seconds for instance, fall from the bulb of the thermometer, Mr. Cavallo brought the mercury down to 3° , or 29° below the freezing point, when the atmosphere was somewhat hotter than temperate. When the ether is very good, i. e. capable of dissolving elastic gum, and has a small bulb, not above 20 drops of it are required to produce this effect, and about two minutes of time; but the common sort must be used in greater quantity, and for a longer time; though at last the thermometer is brought down by this very nearly as low as by the best sort.

The proportion of ether requisite to congeal water, seems to vary with the quantity of the latter; that is, a large quantity of water seems to require a proportionably less quantity of ether to freeze it than a smaller one. "In the beginning of the spring (says Mr. Cavallo) I froze a quarter of an ounce of water with about half an ounce of ether; the apparatus being larger, though similar to that described above. Now as the price of ether sufficiently good for the purpose, is generally about 18 pence or two shillings per ounce; it is plain, that with an expence under two shillings, a quarter of an ounce of ice, or ice cream, may be made in every climate, and at any time, which may afford great satisfaction to those persons, who, living in places where no natural ice is to be had, never saw or tasted any such delicious refreshment. When a small piece of ice, for instance, of about ten grains weight, is required, the necessary apparatus is very small, and the expence not worth mentioning. A small box four inches and a half long, two inches broad, and one and a half deep, contains all the apparatus necessary for this purpose; viz. a bottle capable of containing about one ounce of ether;

ether; two pointed tubes, in case one should break; a tube in which the water is to be frozen, and a wire. With the quantity of ether contained in this small and very portable apparatus, the experiment may be repeated about ten times. A person who wishes to perform such experiments in hot climates, and in places where ice is not easily procured, requires only a larger bottle of ether besides the whole apparatus described above.

TO PRODUCE A GREAT DEGREE OF COLD.

The power of producing cold belongs particularly to bodies of the saline class. In a paper of the Philosophical Transactions, Mr. Geoffroy gives an account of some remarkable experiments with regard to the production of cold. Four ounces of sal-ammoniac dissolved in a pint of water, made his thermometer descend two inches and three quarters in less than fifteen minutes. An ounce of the same salt put into four or five ounces of distilled water, made the thermometer descend two inches and a quarter. Half an ounce of sal-ammoniac mixed with three ounces of spirit of nitre, made the thermometer descend two inches and five lines; but on using the spirit of vitriol instead of nitre, it sunk two inches and six lines. In this last experiment it was remarked, that the vapours raised from the mixture had a considerable degree of heat, though the liquid itself was so extremely cold. Four ounces of salt-petre mixed with a pint of water, sunk the thermometer one inch three lines; but a like quantity of sea-salt sunk it only two lines. Acids always produced heat, even common salt with it's own spirit. Volatile alkaline salts produced cold in proportion to their purity, but fixed alkalines heat.

If, instead of making these experiments, however, with fluid water, we take it in it's congealed state of ice, or rather snow, degrees of cold will be produced vastly superior to any we have yet mentioned. A mixture of snow and common salt sinks Fahrenheit's thermometer to 0; pot-ashes and powdered ice sink it eight degrees farther; two effusions of spirit of salt on pounded ice sink it more than $14\frac{1}{2}^{\circ}$ below 0. This is the ultimate degree of cold that the mercurial thermometer will measure, because the mercury itself then begins to congeal; and therefore we must afterwards have recourse to spirit of wine, naphtha, or some other fluid which will not congeal. The greatest degree of cold hitherto producible by artificial means has been 80° below 0; which was done at Hudson's Bay by means of snow and vitriolic acid, the thermometer standing naturally at 20° below 0. Greater degrees of cold than this have indeed been supposed. Mr. Martine, in his treatise on heat, relates, that at Kirenga in Siberia, the mercurial thermometer sunk to 118° below 0; and Professor Brown at Petersburg, when he made the first experiment of congealing quicksilver, fixed the point of congelation at 350° below 0; but Dr. Black, as soon as the experiment was made known in this country, observed, that in all probability the point of congelation was far above this. His reasons for supposing this to be the case were, that the mercury descended regularly only to a certain point, after which it would descend suddenly and by starts 100 degrees at a time. This, he conjectured, might proceed from the irregular contraction of the metal after it was congealed; and he observed, that there was one thermometer employed in the experiment which was not frozen, and which did not descend so low by a great many degrees. Experience

rience has since verified his conjecture; and it is now generally known, that 40° below 0 is the freezing point of quicksilver.

Since the discovery of the possibility of producing cold by artificial means, various experiments have been made on the efficacy of saline substances in this way; all of which, when properly applied, are found to have a considerable degree of power. Dr. Boerhaave found, that both sal-ammoniac and nitre, when well dried in a crucible, and reduced to fine powder, will produce a greater degree of cold than if they had not been treated in this manner. His experiments were repeated by Mr. Walker, apothecary to the Radcliffe Infirmary in Oxford, with the same result: but he found, that his thermometer sunk 32° by means of a solution of sal-ammoniac; when Boerhaave's, with the same, fell only 28° . Nitre sunk it 19° . On mixing the two salts together, he found that the power of producing cold was considerably increased. By equal parts of these salts, he cooled some water to 22° , the thermometer standing at 47° in the open air. Adding to this some powder of the same kind, and immersing two small phials in the mixture, one containing boiled and the other unboiled water, he soon found them both frozen, the unboiled water freezing first.

The most remarkable experiment, however, was with spirit of nitre poured on Glauber's salt, the effect of which was found to be similar to that of the same spirit poured on ice or snow; and the addition of sal-ammoniac rendered the cold still more intense. The proportions of these ingredients recommended by Mr. Walker, are concentrated nitrous acid two parts by weight, water one part; of this mixture cooled to the temperature 18 ounces, of Glauber's salt a pound and an half avoirdupois, and of sal-ammoniac 12 ounces. On adding the

Glauber's salt to the nitrous acid, the thermometer fell from 50° to -1° , or 52 degrees; and on the addition of the sal-ammoniac, to -9° . Thus Mr. Walker was able to freeze quicksilver without either ice or snow, when the thermometer stood at 45° . For the experiment four pans were procured of different sizes, so that one might be put within the other. The largest of these pans was placed in a vessel still larger, in which the materials for the second frigorific mixture were thinly spread in order to be cooled; the second pan, containing the liquor, viz. the vitriolic acid properly diluted, was placed in the largest pan; the third pan, containing the salts for the third mixture, was immersed in the liquor of the second pan; and the liquor for the third mixture was put into wide-mouth phials; which were immersed in the second pan likewise, and floated round the third pan; the fourth pan, which was the smallest of all, containing it's cooling materials, was placed in the midst of the salts of the third pan. The materials for the first and second mixtures consisted of diluted vitriolic acid and Glauber's salt; the third and fourth of diluted nitrous acid, Glauber's salt, and sal-ammoniac, in the proportions above-mentioned. The pans being adjusted in the manner already mentioned, the materials of the first and largest pan were mixed: this reduced the thermometer to 10° , and cooled the liquor in the second pan to 20° , and the salts for the second mixture, which were placed underneath in the large vessel, nearly as much. The second mixture was then made with the materials thus cooled, and the thermometer was reduced to 3° . The ingredients of the third mixture, by immersion in this, were cooled to 10° , and when mixed, reduced the thermometer to -15° . The materials for the fourth mixture were cooled by immersion in this third mixture to about -12° . On mixture they sunk
the

the mercury very rapidly, and seemingly below -40° , though the froth occasioned by the ebullition of the materials, prevented any accurate observation. The reason why this last mixture reduced the thermometer more than the third, though both were of the same materials, and the latter of a lower temperature, was supposed to have been partly because the fourth pan had not another immersed in it to give it heat, and partly because the materials were reduced to a finer powder.

The experiments were repeated with many variations; but only one mixture appeared to Dr. Beddows, by whom the account was communicated to the Royal Society, to be applicable to any useful purpose. This is oil of vitriol diluted with about an equal quantity of water; which, by dissolving Glauber's salt, produces about 46° of cold, and by the addition of sal-ammoniac, becomes more intense by a few degrees. At one time, when Mr. Walker was trying a mixture of two parts of oil of vitriol and one of water, he perceived, that at the temperature of 35° , the mixture coagulated as if frozen, and the thermometer became stationary; but on adding more Glauber's salt, it fell again in a short time: but less cold was produced than when this circumstance did not occur, and when the acid was weaker. The same appearance of coagulation took place with other proportions of acid and water, and with other temperatures.

It is observable, that this effect of Glauber's salt in producing cold, took place only when it was possessed of it's water of crystallization; and thus the mineral alkali also augmented the cold of some of the mixtures: but when the water of crystallization was dissipated, neither of them had any effect of this kind.

AN ABSTRACT OF M. DE LUC'S VIEW OF GENERAL CHEMISTRY, DEDUCED FROM CONSIDERING THE CHANGE OF ICE INTO WATER, AND WATER INTO ICE.

There is no phenomenon more important than the change of *ice* into *water*, and of *water* into *ice*. Though I have already considered this phenomenon, I shall here again, after M. de Luc, analyse it more particularly, in order to shew you, that it includes the important basis of *general chemistry*. The various operations of chemistry may be reduced to the *uniting* or *separating* of substances: their general immediate cause arises from the different tendencies of the particles which compose those different substances: and the changes which happen in these phenomena are produced by the changes that the *particles* undergo in their composition. Now as the phenomena of *water* and *ice* include all these different kinds of modifications, they will furnish you with a clear and very important idea of the kind of change which is the source of *chemical phenomena*.

Now with respect to ice: 1. It's *particles* cannot be *separated* without a sensible effort. 2. When broken, the portions thereof, although brought within the smallest possible *distance* of each other, shew no *tendency to unite*. 3. When fragments of ice are laid in *heaps*, the respective *adherence* of the particles, joined to their resistance to motion, makes them remain in the same position in which they have been placed. These are strongly marked chemical properties, and the substance cannot be deprived of them, unless the *particles* undergo an essential change.

Water, if you were only to judge of it by *weight*, would be ice itself, for the transformation is made without any discernible change in *weight*; though

though very great changes have taken place in the *ponderable* particles; for, 1. They may be *separated* with the greatest ease, their resistance to separation being almost insensible. 2. They have a tendency towards each other even at a sensible distance; hence small masses, when free, coalesce, and form a spherical drop, the moment they touch; and this is not the effect of *gravity*, but contrary to it. 3. These new *particles* slide so easily one over the other, that, excepting the above-mentioned small masses, they cannot now be laid in *heaps*; but yield immediately to the efforts of gravity, and always become *level*. Let us now consider how these changes in the particles of ice are accounted for. Philosophers are unanimous in allowing that these changes are occasioned by *fire*, a substance without weight. The quantity of this substance that produces this effect, is sufficiently characterized by its peculiar properties; but after this change, these properties are no longer exercised, because the particles of fire are combined with those of *ice*. It is this combination that occasions the chemical changes just described. Now these changes are as essential with respect to physical principles, as any other in the art of chemistry; so that unless established facts should lead us to assign a sensible *weight* to other substances which modify these effects in water, this example alone would authorise us in considering these new substances as *imponderable*, or without weight.

Besides the above-mentioned chemical phenomena, relative to water and ice, there is another very important one, which will serve as a point of comparison. We find from these phenomena but one *ponderable* substance, known by the name of *water*, and an *imponderable* substance called *fire*. Now when the particles of water are in a *liquid state*, a state produced by their union with *fire*, a certain

certain diminution in the quantity of *free fire* will bring them to such a *minimum* of distance, and arrangement in position, that they will unite in a *determined form*, and quit the *fire* which rendered them liquid: or inversely, when the particles of water are formed into ice, if the quantity of free fire interposed therein be sufficient to separate them, it then combines with these particles, and constitutes water; this may be called the *fire of liquifaction*.

Now every attentive philosopher must acknowledge that these are great phenomena, brought about by the combination of two substances, one of which is without *weight*; and that these phenomena are probably the general characters of a particular class. It is to be regretted that the *ponderable* substance, which is common both to *water* and *ice*, has not a peculiar and appropriate *name*, for this substance belongs also to aqueous vapours. Mr. de Luc was once inclined to distinguish it by the term *humor*. You will, I hope, be careful to distinguish the cases in which I shall speak of water as a substance modified neither by *fire*, nor by any other substance. To render you more attentive to this distinction, I shall sometimes use the word *humor*.

The foregoing analysis will enable you more clearly to comprehend the nature of *menstrua*, a class of substances of which the knowledge is very important. I shall confine myself to a few instances.

The name of *acids* has been given to *liquid* substances, which seem to be nothing more than water joined to certain *imponderable* particles. Thus acid liquors are to be distinguished from the acids themselves.

The general phenomena of *acid liquors* are the *affinities* exercised by their particles, as well
amongst

amongst themselves as upon other substances. But *water* (considered here as humor) being united to fire, exercises certain affinities, as well in itself as upon other substances: other particles, therefore, as *imponderable* as fire, may produce such changes therein as may alter, in some respects, it's natural *affinities*; and we are authorized to think that this is the case, unless the supposition be contradicted by facts.

To see this, let us examine the formation of acid liquids, and also their different products: Now when acid liquids are formed, we have every reason for supposing the presence of *water*, either in the solid or liquid substances employed, or in the *vital* or *atmospheric* air, which on decomposition is joined thereto. Those who adopt the hypothesis of *M. Lavoisier* may object to the presence of water in these airs: for in the combustion of sulphur, or phosphorus, &c. they consider *vital air* as the *acidifying* principle, and the substances as *acidifiable* bases. But this supposition is neither necessary nor natural. It is not necessary, because the phenomena may be as well explained without it. If there be a sufficient quantity of *vital air*, all that we perceive is, the production of an acid liquor; i. e. (according to our opinion) a quantity of water whose particles are united to an acid. Now if water is the *ponderable* part of all aeriform fluids, an hypothesis which is sufficient to account for every chemical phenomenon, and is the only one that accords with meteorological phenomena; it is easy to conceive, that on the decomposition of *vital air*, a quantity of water united to acid particles may be liberated. For example, we consider sulphur as containing an *acid*, *phlogiston*, *fire*, *water*, and other unknown ingredients, combined together in a *solid* form (of which I shall treat hereafter): that *vital air* contains *water* and *fire*, which at a certain degree of heat

heat acquire the power of uniting with *phlogiston*; and thus you perceive, as far as it is possible to see into nature, why on the decomposition of these two compounds by combustion, a liquor results, in which the particles of water are united to an acid, distinguished by the name of the *vitriolic*.

With respect to the French hypothesis, it should seem, that every man would consider himself as relieved of a burden, when he found it no longer necessary to admit a substance, which, without being *acid* itself, was yet the cause of *acidity*. Further, though acids may be supposed to exist, they can only act in *liquids*, or *expandible fluids*. So that these operations, instead of furnishing us with an idea of *acidification*, of which we have no conception, leads us only to consider these acids as liberated, and enabled to act by their union with a liquid.

It may therefore be asserted, with confidence, till something more solid is produced, that the operations by which acid liquids are formed, consist in liberating water and the acid particles from their preceding combinations; and thus to produce water charged with certain particles to which *no weight* can be assigned, and which are only discerned by their properties in the substances containing them. Now as soon as the water thus modified receives the *fire of liquifaction*, its particles being free to follow their tendencies, enter into new combinations, by means of the acid particles from which it has received these new faculties. Let us then pursue these particles in the exercise of their acquired tendencies; and first in the phenomena of the *congelation* and *liquifaction* of the liquids they form.

The *water of acid liquors* preserves its general faculty of existing, according to the difference of *temperature*, in a solid or liquid form; but it

has undergone two changes, one, by which it's *particles* do not abandon the *fire of liquifaction*, but by a greater diminution of *heat*; by the other, when they do abandon it and unite, they assume a different arrangement. Here we only perceive different specific characters of the same generical modification. The particles of water (*humor*) whether alone, or whether combined with an acid, can unite with the fire of liquifaction; but in the last state they preserve it in a lower degree of heat; and when they lose it, instead of grouping themselves like pure water in a form in which their volume is increased, they, on the contrary, occupy somewhat less room.

By the experiments of Mr. M'Nab, at Albany, in Hudson's-Bay, we find, that spirit of nitre undergoes, according to it's degrees of *acidity*, two kinds of congelation, distinguished by Mr. Cavendish into the aqueous and spirituous. In the first, the *ice* being produced by the pure water, swims above the rest of the liquid; in the other the liquid itself freezes, and the ice thereof falls to the bottom of the part yet liquid. In the last phenomenon the point of congelation changes with the degree of acidity, but is far from following the laws thereof.

Mr. Cavendish had determined by other experiments, that the true point of congelation cannot be obtained, but by preserving therein some *icicles* of a former congelation. It is thus that the points of congelation in the following table were determined: the degrees of *acidity* of the spirit of nitre are expressed by the quantity in weight of marble it was able to dissolve, compared with it's own weight. The thermometer used was on the scale of Fahrenheit; the correspondent terms are the results of experiments, reduced to a regular series of degrees of *acidity*.

Spirituous

Spirituos Congelation.

Degrees of acidity.	Point of congelation.
0.568 -	—45.5
0.538 -	—30.1
0.508 -	—18.1
0.478 -	—9.4
0.448 -	—4.1
0.418 -	—2.4
0.388 -	—4.2
0.358 -	—9.7
0.328 -	—17.7
0.298 -	—27.7
0.243 -	—44.2

Aqueous Congelation,

Degrees of acidity.	Point of congelation.
0.243 -	—44.2
0.210 -	—17.9

beginning of the aqueous congelation.

From these phenomena, analysed according to Mr. de Luc's theory, it appears, 1st, That by a degree of acidity = 568, fire may remain combined with the particles of water (humor) even as low as —45.5 of Fahrenheit. 2^{dly}, That as the degree of acidity is successively weakened, the particles of water acquire the faculty of uniting at higher temperatures, and of quitting the fire of *liquifaction*; but this progress towards a maximum, which is at a degree of acidity nearly a mean between the two terms of spirituos congelation, the acidity is then 418, and at —2.4 the particles of water unite. 3^{dly}, The acidity continuing to be diminished to 298, the particles of water lose successively the power of approaching without ceasing to be liquid, so much so, that at this point fire is ready to combine with them at 22.7. 4^{thly}, This loss of power relative to the particles of water, continues till the *acidity* is reduced to 243, and at this point the fire of liquifaction does not quit them, but at the temperature of —44.2, which very nearly corresponds to what happened at the greatest acidity 568: but now a new phenomenon takes place; the particles of water being less charged

charged with acidity, again tend to crySTALLIZE in their own way, and those that are most favourably disposed thereto, quit their *acid* and the fire of liquifaction, and become common ice. Lastly, from this point, the more the acidity is diminished, the sooner the particles of water unite, so that when the acidity was only 210, ice (of pure water) was formed at the temperature of 17. These singular phenomena are not peculiar to spirit of nitre, they have been also observed in spirit of vitriol, as may be perceived by the result of experiments formed into a table.

Strength.			Freezing point.
977	-	-	+ 1
918	-	-	- 26
848	-	-	+ 46
846	-	-	+ 42
758	-	-	- 45

From hence we may conclude, that oil of vitriol has not only a strength of easiest freezing, but even a strength superior to this; it has another point of a contrary flexure, beyond which, if the strength be increased, the cold necessary to freeze it again begins to diminish. From the weakest degree of the acid 758, to that of 848, there is an increase of 91° in the freezing point. The acidity increasing to 918, the freezing point falls again 72°, and rises 27, when the acidity becomes 977.

Now there are in these phenomena of *acid liquors* no symptoms which suffer us to consider them as simple substances *ponderable* in their nature, or as compounds of two substances, the one *acidifiable*, the other *acidifying*, and both *ponderable*. According to the first of these notions, in which the acids are considered as *dissolved* in water, we find no point at which to stop in order to determine

termine their proper weight; in the water they are only perceived by their effects, in other compounds they are not discerned: thus, nothing here hinders our considering them as *imponderable*, if other circumstances conduct us to this conclusion. The second notion seems to exclude this supposition, because a known *weight* is attributed to the acidifiable and acidifying particles; but the foregoing experiments deprive this idea of all probability; it cannot explain the extraordinary changes in the *freezing point*, occasioned in the same ponderable substance, merely by the addition of more or less water.

But to be more particular, when the ponderable part of *vital air* is employed as an *acidifying* principle to produce an *acid*, is it a *liquid*, a substance by its nature capable of being *frozen* and *liquified*? Here the advocates for this theory leave us in the dark; we call in vain for explanation. If the *ponderable* part of *vital air*, by being joined to the *ponderable* part of *inflammable air*, produces water, can it in the same operation, the combustion of *sulphur* for instance, produce an *acid*? Here also we receive no explanation. If in the combustion of *fulphur*, part of the *vital air* is used to form an *acid*, part with *inflammable air* to produce water, what is the ratio of the two portions? By what means shall we distinguish them? What is the *acidifiable* substance in *fulphur*, distinct from *inflammable air*? The partizans of the French theory are obdurate, and will afford us no explanation. If, instead of this obscure theory, you consider the water formed by the two airs to be united to an acid, the whole is readily explained, and the double flexure of the freezing point easily understood.

From the *crystallization* of pure water, we learn, that its simple particles are of a certain form,

form, and that they tend towards each other by certain determined sides. Now the different combinations of the acid with the particles of water may change the tendency of these to collect themselves together, and occasion the above described flexures: how this is effected, might easily be shewn by geometry, though it cannot be rendered a subject for these Lectures.

It does not appear that the difference in specific gravity between acid liquors and water is owing to any *ponderable* substance added to the water; but rather to this, that the particles of water are joined to an imponderable substance, by whose means they may be brought nearer to each other without quitting the fire of liquifaction. Now all the preceding phenomena confirm this theory; for they prove in general, that the particles of acid liquors may be brought much closer together than those of water, without losing the fire of liquifaction; and you will presently see, by a very clear example, that the causes which influence the *freezing point*, extend their effect to the general state of liquids. I shall first, however, mention another phenomenon, which furnishes a direct proof of the supposition before us.

If you mix pure water with an acid liquor, the specific gravity of the mixture is greater than the mean of the specific gravities of the ingredients: a clear proof that the acidity causes the particles of water to approach, following an increasing law therein; because the mean approach of the particles is greater than the mean acidity of the united masses. This is also confirmed by a simultaneous effect, that is, the sudden effect of the pressure on the free fire of the mass, which augments the heat thereof; as a bar of iron is heated by forging. The preceding remarks on acid liquors apply so naturally to alkaline liquors, that

it will be unnecessary to mention them here. In neither is there any thing which leads us to think, that the difference of acid and alkaline liquors from pure water depends on *ponderable* particles.

From the union of acid and alkaline liquors result *saline liquids*, from which afterwards by simple evaporation we obtain *neutral salts*, that is, solids of a certain form, which do not receive the fire of liquifaction at the temperature of the atmosphere, unless we restore to the salt the water that was *evaporated* from it. Now if acid and alkaline liquids are nothing but water modified by certain different particles, their solid products should be nothing more than water itself, modified by the union of these particles; and this the water of crystallization directly authorizes us to conclude. Let us then consider this phenomenon further. In some *salts*, after the water of crystallization is evaporated, the remaining mass is no longer capable of being liquified without an addition of water; in others, the mass may be liquified alone, by a great degree of heat. Now here, we only see the modifications of the general phenomena of this class; namely, different combinations of the particles of water with certain other particles, which changes considerably their faculty of receiving the fire of liquifaction; and we even see, these combinations of water may be such, that it's particles refuse to receive the fire of liquifaction, in some cases without a great degree of heat; but even absolutely in other cases.

If, after *salts* have been reduced by evaporation to a *refractory state*, the water which was evaporated be restored with a small addition, the molecules of water, which form the sensible mass of the mixture, re-acquire the fire of liquifaction at the temperature of the atmosphere, and we obtain *saline liquids*.

Dr.

Dr. Blagden, in his paper on congelation, has shewn, that all liquids, susceptible of being frozen, would, like water, bear to be cooled several degrees below the freezing point without congealing. Under the same circumstances acid, alkaline, and saline liquors, have the same property; a further proof that they are the same substance differently modified.

Saline liquors quit the fire of liquifaction sooner than pure water; but attended with another circumstance, still confirming the idea of their being a modification of water. When acid and alkaline liquors freeze, the particles of water therein are so arranged as not to occupy a greater space, which you have seen was the case with pure water; but this property appears again in their *compound* saline liquids.

Thus when the particles of acids and alkalies separately modify the molecules of water, the moment that these lose the fire of liquifaction, they are grouped into solids, which occupy less space than was before occupied by the molecules which compose them; but if the particles of water are modified by those of an acid and alkali, they arrange themselves as if it were pure, but only slower, exhibiting only varieties in the modification of the same substance. *Oils* are, probably, nothing more than water modified by imponderable substances, among which we are to reckon phlogiston.

There is no phenomenon of acid, alkaline, and saline liquids, which can lead us to assign a discernible weight to any other particles but those of pure water.

In all these phenomena we only perceive the developement of an ancient principle of chemistry, *that no substance can act chemically, unless it be dissolved*; for in order that the particles of any substance may obey it's respective tendencies, they must have liberty to move, and this they can only have in

liquids and expansible fluids. The particles of water, from their faculty of being united with fire, are susceptible of liquidity, and when in this state, can obey either their natural tendencies, or those they may have acquired by combination. It is thus that water becomes the *universal menstruum*; that is, by it alone all other menstrea exist, because it's particles will acquire as many various tendencies, as there are species of subtil particles to unite therewith, either separately or conjointly. Among the changes in tendency, which take place in the particles of water, there is a class of great importance in the operations of nature; namely, that which relates to their different aptitude of receiving, and of retaining the fire of liquifaction; from whence, besides different liquid states, they are capable of assuming a great variety in a solid form, the solidity depending principally on this, that the particles are not capable of being united with the fire of liquifaction, but at a certain temperature, or by the addition of certain ingredients. *Salts* are, hitherto, the only solids we have considered as produced by water; with respect to these, *pure water*, whether liquid, or as ice, is a *flux*, by means of which they are fusible at the temperature of the atmosphere, nay even at a low temperature; but conducted by analogy, we may proceed further in the abstract analysis of solids.

When you consider all the solids on the surface of our globe, as well organized bodies, as natural fossils, and examine the certain and uncertain results of our analyses, you will not be able to trace in these bodies any substances *ponderable* in themselves, but *water* and *elementary earths*, taking the term, elementary earth, in a general sense. Among the substances, which are not discernible by their weight, we have *light*, *fire*, *electricity*, *acids*, *alkalies*, *phlogiston*, and the peculiar particles of cer-
tain

tain airs. Every terrestrial phenomenon seems to announce other imponderable substances; and from hence you may conceive how many causes of this class are concealed from us by our ignorance.

Such then are the substances by which the immediate physical causes produce the phenomena of our globe; the *ponderable* substances are water (humor) and earths; the remaining terrestrial substances consist only of particles of different classes, but of such subtilty, that whatever be their quantity in the masses that we *weigh*, their *weight* has hitherto escaped. Water will unite with all these particles, but at different degrees, and acquires by the union different affinities, from whence immediately result various liquids, expansible fluids, and some solids, which are fusible at different temperatures of the atmosphere, either immediately, or with water for their flux. By these combinations in different states with the earths, solids are produced, on which these means of liquifaction have no power. All these combinations can only take place in *liquid* water, in which they have an opportunity of exercising their affinities: and when solids are formed therein, it is in certain cases, by the addition of some substances, and the simultaneous emission of some expansible fluids. These solids are no longer solvible in the remaining fluid, and in order that it may dissolve them, they must be deprived of their additional substances, and their expansible fluids must be restored to them. Now with respect to the greater part of the solids of our globe, as well those which were formerly formed on it's surface, as those which are daily forming there, these combinations are the great secret of nature.

The preceding analysis developes this ancient *principle* of chemistry, *that fire is the agent of all dissolution*. This proposition is true, but only,

mediately; for *light* is the first agent of every chemical operation. By *light* united to some substance hitherto undetermined, *fire* receives its existence. By *fire* the particles of water (humor) receive their liquidity, that is, the power of obeying, although contiguous to each other, not only their own tendencies, but those they acquire by the addition of other particles. By these additions the particles of water are more or less disposed to retain or to receive the fire of liquifaction.

Marine salt may be considered as a refractory solid, and common ice as a fusible solid. These two solids being mixed above a certain temperature, have the power of seizing in common the fire of liquifaction at all points where they touch. This is the general principle of other fusions by fluxes. For experiment teaches us, that certain solids being mixed can receive the fire of liquifaction, whence the affinities of their ingredients have an opportunity of acting. Experiment has also shewn, that in order that they may receive more easily the fire of liquifaction, or that in their common liquifaction, the solids designed to be produced may be formed, or even separate themselves by a difference in specific gravity, they must be deprived of certain ingredients. Now here again fire comes in to our aid; by its agency, and that of atmospheric air, certain expansible fluids are formed, others are absorbed, and the solids thus torrifed are ready to go into the furnace, and receive the fire of liquifaction.

ON WATER IN A STATE OF VAPOUR.

Though I have explained in my Lectures on fire the more particular phenomena that take place in the passage of water into vapour, I have also shewn you, that water heated to 212° , when the barometer is $29\frac{1}{2}$, flies off in vapour, and becomes an elastic fluid, at least 800 times more rare than air. This elastic

elastic fluid or steam is the most powerful agent that can be applied to working of engines, where great mechanical power is required. This subject being thereby rendered of the greatest importance to arts and manufactures, you will not, I hope, think your time misapplied in reconsidering the nature of this wonderful agent; the more as it will in some respects be exhibited under a different point of view, and with some circumstances which we did not before attend to.

The quantity of fire necessary to turn water into steam is immensely great, as you may easily convince yourselves from the operation of a common still, by observing the vast heat received by the water in the worm-tub used to condense the vapour. You may strengthen this idea by considering, that if a vessel of water be placed on a good fire, and that though you increase the power of this fire to the highest degree capable by human art, yet you cannot raise the temperature of the water above the boiling point. Now what can become of the vast accession of fire which the water in the vessel is constantly receiving. It goes off with the steam raised from the water, and may be again obtained from it by condensing the vapour. If you prevent the steam from flying off, as in Papin's digester, it will retain the heat it has acquired from the fire; where the confined water will be found so hot as even to dissolve bones, and to produce such effects as I have already described to you. Yet this fire, when combined with the vapour, is as it were neutralized and rendered with respect to external objects quiescent.

To estimate the expansive force of water reduced into vapour, I know no instrument so convenient as that of Mr. le Chevalier de Bettan-

court.* It consists of a vessel A placed upon a chafing dish B, having one opening at top, to which a curved barometer is adapted, and another to which a thermometer is filled, and a third with a cock; these are, you see, so disposed, that when the cock is shut there is no communication between the interior space and the exterior air.

When the cock is open, and the water is not heated, the mercury will, of course, be at an equal height in each of the branches m, m. If the air be then exhausted from the large vessel A, and the cock be shut, the mercury will rise from m to k in one branch, and descend from m to k in the other; so that the water being supposed to be at the freezing point, the difference between k and k will be 28 inches.

Let the water be heated rapidly, and you will perceive the first signs of ebullition by it's striking against the vessel, which it will do with so much force as to shake the whole apparatus; at the same time the mercury in the thermometer will rise, and that in the barometer will fall; and when the mercury is at the same height in each leg of the syphon, the thermometer will be at 212° , the pressure of the steam at this temperature being an exact counterballance to the weight of the atmosphere. If you now increase the heat of the water, the mercury will rise in the branch on which the air presses, and descend in the other; the difference will depend on the temperature of the water, or increased expansive force of the steam. If you add to this difference in the two columns of mercury, the height of the mercury in a common barometer, their sum will express the height of a column

* See fig. 11, of pl. 6. vol. i. I have before observed, that the Lectures on water were originally designed to make a part of the first volume.

column of mercury, representing the expansive force of the steam. The difference in the level must be used positively or negatively, according as the thermometer is above, or under 212.

There is no occasion for two barometers; if the open end of this was sealed, it might then be filled like a syphon barometer.

With this apparatus Mr. Bettancourt made a variety of experiments, the results of which are given in the following table:

T A B L E.

Degrees of Reaumur's thermometer.		Expansive force.
0	—	0.00
10	—	0.15
20	—	0.65
30	—	1.52
40	—	2.92
50	—	5.35
60	—	9.95
67	—	14.50
70	—	16.90
86	—	28.00
90	—	46.40
95	—	57.80
100	—	71.80
104	—	84.00
110	—	98.00

When vapour is exposed to a great heat, it's bulk, as you have seen, is considerably augmented; at 212° water is only rarified to 26; but with the same degree of heat vapour is expanded to 13 or 14000 times the volume which it occupied as water. Of this you may easily assure yourselves, by taking a glass tube with a ball at the end thereof 2 inches diameter; let a drop of water pass into the ball of one line diameter; the solidity of these two spheres will be to each other as 13824

to 1. Heat the ball so as to convert the water into vapour, and it will fill the whole sphere, and force the air out of the ball, as you will find by immersing the end of the tube in water, a little warm, lest the sudden application of cold should burst the ball; and in proportion as the vapour is condensed by cold, the pressure of the atmosphere will force the water into the ball so as to fill it entirely; proving thereby that the vapour had forced the air out of it, had assumed a bulk near 14000 times larger than it occupied as water.

It is impossible to give you an accurate idea of a steam-engine without a model. I shall therefore content myself in this place with laying before you a few of the general principles on which it acts. It has been shewn you in the Lectures on air, that the pressure of the atmosphere, at a mean, may be estimated at 14.8 pounds avoirdupoise for every square inch.

If therefore a vacuum be by any means made in a cylinder, which is furnished with a moveable piston, suspended at one end of a lever, or ballance beam, the pressure of the atmosphere will press down the piston with a force proportionable to the area of the surface, and will raise an equal weight at the other end of the beam.

Water, as you have seen, may be rarified near 14000 times, and was capable of forming a vacuum by a degree of heat capable of keeping water in a boiling state: by increasing the heat you have also seen, that the expansive force of the steam may be rendered much stronger. The steam may be condensed or reduced to water by a jet of cold water dispersed among it, so that 14000 cubic inches of steam may be reduced into one cubic inch of water only, and thus a vacuum is partly obtained.

Though the pressure of the atmosphere be about $14\frac{8}{10}$ pounds upon every square inch, yet on account

account of the piston of the several parts, of the imperfection of the vacuum, the piston in the common engines does not descend with a force exceeding 8 or 9 pounds upon every square inch of it's surface. In Mr. Watt's improved engine, are about 12 pounds and a half upon every square inch.

The piston being pressed by the atmosphere with a force proportionable to it's area in inches, multiplied by about 8 or 9 pounds, depresses that end of the lever, and raises a column of water in the pumps at the other end of the beam equal to that weight. When the steam is again admitted, the piston is forced up by it's expansive power, and the pump rods sink; but when the steam is condensed, the piston descends, and the pump rods rise; and so alternately as long as the engine works.

MR. DE LUC'S THOUGHTS ON THE STATE OF AQUEOUS VAPOUR IN THE ATMOSPHERE AND LAWS OF EVAPORATION.

As no person has paid so much attention to meteorology and the branches of philosophy relating thereto, as Mr. de Luc, I should not think I had given you an accurate idea of this subject without laying before you the result of his experiments and observations; and I may venture to assert, that you will make very little progress in this part of philosophy, unless you are master of his principles.

Mr. de Luc's notions concerning rain were first changed from an observation on the *glacier de Buet*, of a degree of *dryness* in the air, absolutely unknown in the valley at the same temperature. This observation, followed by others, led him finally to conclude, "that rain does not proceed from the *moisture* which existed in the atmosphere prior to the formation of the *rainy clouds*."

By experiments with his hygrometer he has shewn, that air may be entirely deprived of the
immediate

immediate product of evaporation; the consequence of which is *absolute dryness*. The same instrument shews, that this product of evaporation has a *maximum*, variable with the temperature, but *constant* under the same temperature. The hygrometer is *fixed* by these two states of air; no method of *drying* or of moistening make it pass beyond these boundaries, which thus become the extremes of a scale, referring to a total cessation or maximum of moisture.

In the same hands the hygrometer has served to fix our ideas of the cause by which water simply evaporated in air may be *precipitated*. These causes are the same with those, which in air, where the quantity of water evaporated does not change, occasion an augmentation of humidity, the necessary forerunner of the precipitation of water. Experience points out two, and only two, the *condensation* of air, or it's being *cooled*. Some philosophers have thought that humidity was increased by rarifying the air; forming their opinion from those experiments, where the air in a receiver, on being rarified, produced a mist or fog. Mess. Wilcke, Nairne, and de Saussure have shewn, that if care be taken to exclude from the apparatus every fresh source of evaporation, the rarification of air promotes *dryness*. The phenomena, on which the contrary hypothesis is founded, arise from water left in the apparatus, and the mist is produced by the acceleration of evaporation in the rarified air, and the instantaneous cooling of the space containing the air. The water which evaporates, preserving sensibly the same heat which acted on it before, fills the receiver with vapours more dense than the maximum relative to the momentary diminution of temperature, consequently they precipitate themselves suddenly. Thus this theory corresponds with the phenomena of the precipitation of water by the rarification

rifaction of air, which is unaccountable on the supposition of the diffolution of water by air: for in the latter hypothesis the particles of water are united by *affinity* to the particles of air. But neither the theory of *affinities*, nor any fact concerning them, authorizes us to believe, that two substances thus united, should acquire a tendency to separate, because the particles of the mixture were removed to a greater distance from each other; a circumstance, which, as it lessens their tendency to each other, ought to give them a better opportunity for exercising their affinity to water.

Humidity cannot therefore be increased by this cause, since the augmentation of humidity would be a sign that water was separating itself more efficaciously from the particles of air. Now in Mr. de Luc's theory, when an aqueous fluid mixed with air produces moisture therein, this moisture must be diminished by rarifying the air. And this is really the case, for there is less water in the receiver after a portion of the vapour has been pumped therefrom. The temperature is soon also re-established by the fire, which passes through the receiver, to supply the place of that which was carried away with the vapour.

Rarifying the air, when the quantity of evaporated water remains the same, is therefore a cause of *dryness*, instead of *humidity*. Now with respect to the other cause of an increase of moisture, the *condensation* of the air, it cannot be supposed in the atmosphere; there remains therefore but one cause by which we can account for the precipitation of water which is evaporated in open air, namely *cold*; and from time immemorial those who have endeavoured to explain rain by this cause, have had recourse to strata of air in motion, which were more or less warm than those they met; but this explanation is also chimerical.

When,

When, in a given mass of air, the evaporated water is at it's maximum in a given temperature; if the heat be increased, the particles separate further, and the air will contain more water. If the particles are brought nearer together, the water superabounds, and the excess is precipitated. These facts are certain. Now let us suppose two strata of air of different temperature meeting each other, each of them containing evaporated water at it's maximum for the respective temperatures; the warmest stratum will lose it's heat, and consequently it's superabundant water; but the other stratum will acquire this heat, and be therefore capable of receiving this superabundant water.

When Mr. de Luc and his brother were at the bottom of the *glacier de Buet* in 1770, it had rained for some time, the valley and neighbouring mountains were imbibed with water. There was also a very great evaporation from the ground of these mountains, which was increased by the quantity of melting ice. They however experienced a degree of dryness unknown at the same temperature upon the plains. Two years after, returning to the same place with an hygrometer, they found that the humidity diminished as they rose, and when they arrived at the summit where the ice was beginning to melt, they found that same extraordinary dryness which had so much struck them on their first visit.

While they were upon the glacier, dry as it seemed to be, some clouds began to form in the stratum where they were situated; they rolled first about the mountain, but they soon were formed throughout the whole stratum, extending to a great distance towards the plains, and increasing with such rapidity, that Mr. de Luc and his brother thought it prudent to descend; the hygrometer still advanced towards dryness. Soon after their
departure

departure from the *glacier*, it was covered with clouds, and before they had attained their lodging there was a heavy rain from the very stratum, which a little before was so exceeding *dry*; the rain continued during the whole night, and part of the next day.

Mr. de Saussure has confirmed these observations of Mr. de Luc by many more, which all tend to prove the great dryness of the atmosphere in these superior regions.

The water which is at the lower part of the atmosphere is continually evaporating and rising in the air, but this evaporation does not increase the moisture therein; for in a dry season it goes on diminishing, the ground at last becomes dry, the vapours discontinue, and the dew ceases every where but near water. This phenomenon does not however appear surprizing to those who imagine, that the evaporated water is collected in the higher regions, where the clouds are formed. But this idea must be abandoned, for we now know, *that in serene weather, before the clouds are formed, and even among the clouds, the upper regions are at least as dry as the lower part of the atmosphere, in it's greatest degree of dryness, at the same temperature.* These clouds are not therefore formed from the moisture of the air. The immediate product of evaporation in some manner changes it's nature in the atmosphere, for it does not sensibly affect the hygrometer; and it's return to a state of aqueous vapour to produce clouds and rain, proceeds from some cause of which we are ignorant.

Of the various hypotheses to resolve this difficulty, that of Mr. de Luc is the most probable, who supposes, *that the aqueous vapours are turned in the atmosphere into an aeriform fluid, and that rain proceeds from the decomposition of this air.* On this hypothesis it is easy to perceive why the hy-

grometer is not affected by the quantity of water that is often existing in the atmosphere.

The difference between *water* as *vapour*, and as an *aeriform* fluid, consists in this; that in *vapour* the union of water with fire is very weak, and is easily destroyed by *pressure* or *cold*; but by the addition of another substance it loses these properties, and becomes an *aeriform* fluid. There are many reasons for supposing that a variety of *aeriform* fluids are included in the atmosphere, which by resisting the operations used to diminish the atmosphere are unknown to us. Now the operation of these, or of other substances in the air, may decompose water considered as an *aeriform* fluid, and thus occasion rain.*

The variations of the barometer seem naturally to lead us to some such conclusion; for when the barometer falls as a sign of rain, it is from a change in the specific gravity of the air; but Messrs. de Luc and de Saussure have proved, that there never is a sufficient quantity of vapour in the atmosphere to occasion the difference produced by this instrument. There are many other phenomena which are not accountable on the usual principles, and conduct us to look for some further change in the theory of the atmosphere.

LAWS OF EVAPORATION BY M. DE LUC.

M. de Luc here, as before, considers moisture in the air, as the modification of a particular fluid, consisting of water and fire, mixed with the air, but *independent* thereof.

He also considers evaporation (which occasions this moisture) as an operation of fire without the interference of air.

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* The reader must be referred to M. de Luc's Letters, to learn why the French theory of the decomposition of water does not apply to this case.

That it is an operation of fire, is plain; for every liquor cools when it evaporates, because the portion of the fluid that disappears, carries away a quantity of fire from the liquor.

Mr. Watt has shewn, that in the ordinary evaporation of water in open air, the quantity of heat lost by the mass, bears to the quantity of water carried away, a greater proportion than that which is found in the steam produced by boiling water. There is, therefore, no room to doubt that steam is formed in the first as in the last case.

Whenever water is in a state of evaporation, an expansible fluid, composed of water and fire, is produced. To this fluid M. de Luc gives the name of steam. I use this and vapour indifferently.

As long as steam exists, it exerts a power of pressure like air itself; but it does not belong to the class of permanent elastic fluids, as it may be decomposed either by pressure or by cooling.

There is, as you have seen, a material difference between what are called *permanently elastic fluids* and *steam*, or the *vapour* of water; the former will undergo every known degree of atmospheric pressure without being decomposed; but vapour is decomposed by too great a pressure. The particles of the water being hereby brought nearer together unite, and quit the fire, which in passing from them manifests it's usual properties.

Permanently elastic fluids cannot be decomposed in vessels hermetically sealed, because they are thereby prevented from receiving the action of the bodies with which they have a greater affinity than with those which support them in an aeriform state; but *steam or watery vapours* may be decomposed in vessels hermetically sealed, from the tendency of the fire with which it is united to an equilibrium; thus, when the exterior heat diminishes, the fire quits the water to re-establish the

equilibrium of temperature. If the fire becomes sufficiently abundant on the outside, it re-enters the vessel, and vapours are again formed.

As the expansive property of vapour depends, every other circumstance being the same, on fire, it is greater in proportion as the particles contain a greater quantity.

It appears, that steam is decomposed either by pressure or by cooling; because at a given temperature it has a certain fixed maximum of density, which increases with the temperature.

Thus, when the fluid is arrived at the maximum correspondent to a certain temperature, it will be decomposed, either by being cooled, its maximum being too great for this temperature, or it will be decomposed by an increase of pressure without any change of temperature; for here its density is too great for that temperature: in either case the water is separated from the fire, which supported it as steam.

The degree of pressure, or expansive force, exercised by steam, or which it can support without decomposition, depends on temperature, and is proportional to its density.

Steam is formed at every temperature where a previous space permits its expansion; but no steam can be formed where it has to overcome an obstacle superior to its expansive power at that degree of temperature; and if it be formed, because the obstacle, or pressure, did not exceed its power, yet if the pressure increases, or the temperature lowers ever so little, it is totally decomposed.

It is these circumstances that determine both the degree of heat at which water begins to boil, and the variations of that degree, according to the variations of pressure; for *ebullition* is that state of a liquid in which steam is continually formed with-

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in itself; notwithstanding the external pressure; and to produce this expansive power in steam, a certain degree of heat is necessary in the fluid, which is determined by the degree of pressure. As for the fixity of the degree of boiling water under a constant pressure; it is produced by the equilibrium between the quantity of fire, which continues to penetrate the water, and that which goes off in steam; the differences which may happen in the quantity of fire that penetrates the water, having no other sensible effect than that of producing a more or less rapid formation of steam.

From hence we may perceive the difference between the phenomena of common *evaporation* and *ebullition*. Ebullition requires a determined degree of heat, because the steam cannot be formed within the water, unless it is sufficiently strong to overcome the actual pressure on the water: but in common evaporation the steam and vapour is formed at the surface of the water by every degree of temperature; for it meets with no resistance, but what it can always overcome; it mixes only with the air, and this it expands in proportion to it's quantity, in the same manner as if it were a new quantity of air.

The steam, formed by common evaporation, is of the same nature with that of boiling water; but with respect to the pressure it undergoes, it is similar to that produced by evaporation under an exhausted receiver. Under the exhausted receiver, the resistance the steam meets with is from itself, and is, consequently, proportional to it's own expansive power. In open air, the part of the whole pressure incumbent on the steam is to that whole, as it's power is to that of the whole mass, the rest of the pressure being supported by the air with which it is mixed; which proportion in the pressure

sure steam undergoes, brings it exactly to that of the first, as is proved by experiment.

When the thermometer is at 65° , the maximum of evaporation in an exhausted receiver,* supports 0.5 inch of mercury in the short barometer gage. That the evaporation in vacuum has the same cause as in open air, is clear from the loss of heat by the liquid in this case, as well as the other: an equal pressure is also produced, and added to that of the air, when the receiver is filled with air, as will appear by the following example:

If the thermometer be still about 95 , and the receiver be filled with air of the same density as that in the room, a barometer placed in that receiver, will stand at the same height as in the open air. If a sufficient quantity of water be introduced for producing the maximum of evaporation, the inclosed barometer, like the gage, will rise 0.5 of an inch.

Now as the barometer is, in every case, a manometer, the phenomena, observed in close vessels, give us a true idea of what happens to steam in the atmosphere. When steam is mixed with air, be the mass shut up in a vessel, or be it in a certain part of the atmosphere, distinct by its place, both fluids will act on the barometer, or on every obstacle, and thus against each other, according to their respective power; because no mechanical cause can produce the decomposition of steam, but by forcing its particles to come nearer each other, than is consistent with the temperature by which they are supported; which case cannot happen in the atmosphere, except by the accumulation of steam in some part of it; since elsewhere it only remains mixed with the air, according to its own laws, as if there were no air.

Mr.

* The mean results of experiments.

Mr. de Luc considers the whole theory of hygrology a science, whose objects are, in general, the cause of evaporation, and the modifications of evaporated water, as comprehended in the foregoing propositions.

The common source of the water thus disseminated in the atmosphere, is the surface of the earth; whence in spontaneous evaporation, both in air, and *in vacuo*, as well as in ebullition, we see water carrying off latent fire.

If the product be collected in a close space, it acts in the same manner as a new quantity of expansive fluid.

It is known, by experience, that an expansive fluid is really produced by ebullition, and by evaporation in an exhausted receiver; and no good reason can be assigned to shew why the cause of evaporation, and it's product, should change in any case only by the presence of air; and on examining what may happen in open air, we find no particular cause of the destruction of that expansible fluid, or any difficulty in conceiving it's dissemination in every part of the atmosphere.

Here we lose sight of steam; for watery vapours are not discernible of themselves, and it is on this account they are not perceived in the atmosphere. Mixed therewith, they are not to be distinguished from it, because they are as transparent as itself. In a vacuum they would be taken for an elastic fluid, if we judged of them only by their mechanical effects, without subjecting them to a chemical analysis. In the air their mechanical action is as little perceivable as that of any scattered particles of air; and we should be ignorant of their function in the atmosphere, if it were not for their property of producing moisture.*

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* See Mr. de Luc's paper in the second part of the Philosophical Transactions for 1792.

OF VESICULAR AND CONCRETE VAPOUR.

When vapour or steam is decomposed, if it be contiguous to substances, whose heat is less than it's own, the fire quits the vapour, and the water is deposited on the surface of the body in the form of dew, and in drops. When the heat is as low as congelation, the vapours are crystallized, and deposited in regular and curious forms.

If there are no substances contiguous to the vapours in the air, the particles of water unite, and form either spherical solid drops, hollow spheres, or congealed icicles.

The solid drops unite and form rain. The icicles are the first elements of snow; but as they are often very minute, and remain suspended in the air, where they produce different meteors, Mr. de Saussure ranks them in the class of vapour, and gives them the name of *concrete vapour*.

The existence of the hollow spheres, or vesicular vapours, has been often supposed, before philosophers were able to exhibit them to the senses. The simplest and most instructive manner of observing them, is to expose a cup of some warm aqueous fluid, of a dark colour, as coffee, or water mixed with ink, to the rays of the sun in a fine day, when the air is very calm; a cloud will rise from the fluid to a certain height, and then disappear. An attentive eye will soon discover that this cloud consists of small round grains, of a whitish colour, and detached one from the other. To acquire a more distinct idea of their form, you may observe them as they rise from the surface of the liquor, with a lens of about one inch and half focus; being careful, however, to keep the lens out of the vapours, that they may not deprive it of it's transparency.

You may thus observe spherical balls of different

ferent sizes proceeding from the surface with more or less rapidity. The more delicate rise with rapidity, and soon traverse the field of the lens; the larger fall back into the cup, and without mixing with the fluid, roll upon it's surface like a light powder, which obeys every impulse of the air, and are blown from one edge of the cup to the other, even when there is no apparent agitation in the air. These globules may be seen on a sudden to begin to move, the smallest rising by an agitation of the air imperceptible to our senses, flying off and disappearing, whilst the largest remain rolling on the surface without quitting it; at other times you see some of them, which were suspended in the air, descend to the surface, and there reel a while like pigeons on a ground fresh sown, then on the smallest agitation rise again, and fly away.

The lightness of these small spheres, their whiteness, &c. gives them an appearance altogether different from solid globules; their perfect resemblance to the larger balls that are seen floating on the surface of the liquid can leave no doubt of their nature; it is sufficient to see them to be convinced that they are hollow bubbles, like those blown from water and soap.

Mr. Kratzenstein endeavoured to estimate their size, by comparing them with an hair, and found they were 12 times smaller than the hair, whose diameter was the 300th part of an inch, and consequently one of these was only the 3600th part of the same measure.

To observe them more readily, Mr. de Saussure used a kind of eolipile, formed of two balls, i. e. a glass tube sealed at A, *fig. 10, pl. 5, vol. i.* open at D; the two balls communicating with each other, and the opening or neck D. He let

some drops of water pass into the ball B, and placed it over the flame of a spirit of wine lamp; spirit of wine was used that the balls might not be obscured; as soon as the water is sensibly heated in the ball B (the ball C being yet cold), you may see the vapours from the ball B enter into the ball C, and there condense themselves in the form of a cloud, which is entirely composed of these vesicles; but when the water boils in B, the torrent of elastic vapours that enter C warms this ball, and the vapour being no longer condensed, neither cloud nor vesicles are seen; it becomes perfectly transparent, and the jet proceeds from the neck B, as from an eolipile. If you then remove the eolipile from the flame, and cool, by means of cold water, the ball C, the vesicular vapours will again appear: by placing this ball on the stage of a microscope, you may observe these vapours with the greatest convenience.

You may even, sometimes, be able to observe them in a fog, or in a cloud when on a hill: to this end Mr. de Saussure used a lens of one and a half or two inches focus, which he held near his eye with one hand; in the other he held any smooth, flat, and polished surface of a black colour, as the bottom of a tortoiseshell box; bringing this towards the lens, till it was very near the focal distance thereof, he then waited till the agitation in the air brought some particles of the cloud into the focus of the lens; when the cloud was thick, this soon happened, and he perceived round and white particles passing with the rapidity of lightning, others moving slowly, some rolling upon the surface of the tortoiseshell, others striking against it obliquely, and rebounding like a ball from a wall, others fixing themselves thereto. Small drops of water might also be perceived to settle on the tortoiseshell; but they

they were easily distinguished from the hollow spherules, by their transparency, their gravity, and their pace.

Further, clouds do not form a rainbow; it is produced by solid drops; when a cloud is not in an actual state of resolution, it does not change the form of the stars that are seen through it; for infinitely thin meniscusses do not sensibly change the course of the rays of light. But as soon as the cloud begins to resolve itself in solid drops; even without clouds, when solid drops begin to be formed in the air, the stars seen through them are ill defined, surrounded with a diffuse light, circles, and halos; hence these meteors are the forerunners of rain, for rain is nothing more than these drops augmented or united. When the vesicular vapours are condensed by cold, the water which formed the bubble crystallises, sometimes into hoar frost, sometimes into snow; when it does not freeze, they unite in dew, or descend in rain. Many other curious properties concerning the vesicular and concrete vapours are related in Mr. de Saussure's excellent *Essai sur l'Hygrometrie*.

OF MINERAL WATERS.

A full investigation of the properties of mineral waters is the subject of chemistry; but since the discoveries of Dr. Priestley it has so much analogy with philosophy, that I cannot pass it over entirely in silence.

The name of mineral water is in general given to any water which is found to be so loaded with foreign principles as to produce a different effect on the human body from that which is produced by the waters commonly used for drink. Our ancestors were particularly attentive to procure
wholesome

wholesome water; it was this that determined where they would unite together, and regulated their choice of the situation of houses. *Hippocrates*, the father of medicine, was well acquainted with the influence of water upon the human frame, and affirms that the mere quality of the usual drink is capable of modifying and producing a difference among men.

When we consider that many of the ancient philosophers supposed that all things were originally derived from water, it is evident they must have had an extensive view of the operations of nature. We see that it produces dew, clouds, rain, snow, and other meteors; nor can we help observing how every vegetable, and every animal, rises out of it. When we chemically examine the materials of which animal and vegetable substances are composed, we find water to be a principal ingredient. Nothing then remains but the solid and inanimate parts of the globe; the various earths, rocks, stones, and minerals, of which the dry land and vast mass of mountains are composed, even these, the more we examine them the more we have reason to think, derive their origin from water.

In marble, chalk, and limestone, we find evident traces of the sea; we cannot rationally think otherwise of these strata, than that water has been greatly concerned in their origin. And further, as we find these strata irregularly mixed with the hardest rocks both above and below, we must consider them as springing from the same source. On examining the rocky strata, you will find marks which plainly point out that they originate from the *sea*. Thus the strata of freestone which are very extensive, evidently shew from their appearance that they were originally sea-sand; they are divided into small strata, and are distinguished into
horizontal

horizontal layers, and have the same undulated surface as the sand of the sea-shore.

Flinty substances seem to form the strongest objections to this system, as they resist the action of water as much as any substances in nature: but there are many phenomena in nature which shew that calcareous earth is convertible by length of time into a flinty matter; and marine shells are not unfrequently met with which have lost their calcareous nature, and are converted into the hardest and purest flint. In bitumen and coals we find evident traces of a vegetable origin.

The analysis of water is not only useful in a physical point of view, but also as an object of medicine, in order to determine whether any water is useful, to know those which possess medicinal virtues, and apply them to the uses to which they are suited; or to appropriate to different works and manufactories the waters best calculated for their respective purposes, to correct impure waters, and lastly to *imitate the known mineral waters* at all places, and at all times. Whether you consider mineral waters with respect to their formation, or the benefit which accrues from them, we have reason to estimate them as precious gifts of *Divine Providence*. But it is with these as with many other blessings, we are too often heedless and ungrateful. "How many, for whom the wonders of creation, providence, and redemption, have been wrought, that think them not worthy their attention! Angels admire and adore, where man will not deign to cast an eye, or employ a thought."

The mineral waters are divided into different heads, according to the substances they contain:

1. The *acidulous*, which contain an aeriform fluid, which gives these waters a briskness like that of a fermenting. This briskness is most apparent when

when the water is poured from one vessel to another; it is sometimes so considerable as to burst the bottle. They redden the tincture of turnsole, and precipitate lime-water.

2. An acid is sometimes found in the waters of springs, giving them a very sensible acidity; this generally arises from the vitriolic acid: this acid has, however, in general, so strong a disposition to unite with the various substances through which the water of a spring passes, that it is seldom found in a separate state in the water.

3. An alkaline salt is sometimes met with in water; this is in general the fossil alkali.

4. Neutral salts. Of these, those that are most generally found are common salt, and sometimes nitre.

5. Earthy substances. Of these the calcareous is sometimes found. There are mineral waters which contain so much calcareous earth, as to become petrifying to other bodies.

6. Earthy compounds. Thus you may often find calcareous and other earths suspended in water by means of an acid. Thus gypsum is contained in almost all waters, Epsom salt is found in great quantities, and allum is sometimes to be met with.

7. Sulphureous waters. These waters have been long considered as holding sulphur in solution; but Bergman has proved that most of these waters are more impregnated with hepatic gas: this class is known by emitting the smell of rotten eggs.

8. Martial waters. These have a very astringent taste, and exhibit a blue colour by the solution of precipitate of lime. The iron is held in solution either by fixed air, or the vitriolic acid.

Sometimes the acid is in excess, and the waters have a penetrating sub-acid taste, as Pyrmont and Spa water.

Sometimes

Sometimes the acid is not in excess, and the waters are not acidulous.

In chemical writers you will find the method of analysing these different waters. When the analysis is well made, the synthesis is no longer difficult. And the imitation of mineral waters is now no insoluble problem. The processes of nature are inimitable only in those operations that are vital. In this instance we can do more than imitate, we can vary at pleasure the nature and proportion of the constituent parts, and give them, as circumstances require, more or less energy. In artificial waters the ingredients are known, while the ingredients of waters in their natural state are always unknown.

That which Dr. Johnson has observed of a poet is equally applicable to a philosopher. To him nothing can be useless. Whatever is beautiful, and whatever is dreadful, should be familiar to his mind; he should be conversant with all that is awfully vast, or elegantly little. The plants of the garden, the animals of the wood, the minerals of the earth, and the meteors of the sky, should all concur to enrich his mind. By him no kind of knowledge should be overlooked, he should range mountains and deserts, explore every tree of the forest and flower of the valley, the crags of the rock, the mazes of the stream, and the great wide sea, with it's unnumbered inhabitants; he will find them all

—speak their Maker as they can,
But want and ask the tongue of man:

calling upon him to praise his redeeming God,
who in the intellectual, as in the material world, is
LORD and KING; who is obeyed by the angels in
heaven, served by the church upon earth, and feared
by the spirits imprisoned in deep places beneath.

Look at every thing in nature; look at all the variety of creatures therein; consider it in all it's height and depth, in all it's variety of operations; and you will find it is only for this end, that it may in it's infinite variety of degrees and capacities manifest the hidden riches, the invisible powers, and glories of the spiritual world; and be as so many sounds and voices, preachers and trumpets, giving glory, praise, and thanksgiving to the God OF LOVE.

The present Lecture has afforded you fresh instances of the wonders and variety, the harmony and magnificence discoverable in the works of God. There is not, for instance, in nature a more august and striking object than the *ocean*. It's inhabitants are as numerous as those on land; nor is the wisdom and the power of the Creator less displayed in their formation and preservation, from the smallest fish that swims to the leviathan himself. Nor is there any image which gives us a grander idea of the power and greatness of God, who hath this raging element so much under his command: hence he is represented in holy writ as holding it in *the hollow of his hand*.

There the creatures of God multiply in a much greater proportion than by land, and are maintained without the cost or attendance of man; they are a singular flock, which have no shepherd but the CREATOR himself, who conducts them at different seasons in innumerable shoals to supply the world with nourishment.

By means of navigation Providence hath opened a communication between the most distant parts of the globe; the largest solid bodies are wafted with incredible swiftness upon *one fluid* by the *impulse* of another, and seas join the countries which they appear to divide.

The waters of the sea are not only prevented from destroying the earth, but by a wonderful machinery are rendered the means of preserving every living thing which moveth thereon. Partly ascending from the great deep through the strata of the earth, partly exhaled in vapour from the surface of the ocean into the air, and from thence falling in rain, especially on the tops and sides of mountains, where they break forth in fresh water springs, having left their salts behind them; they trickle through the valleys, receiving new supplies as they go; they become large rivers, and after watering by their innumerable turnings and windings immense tracts of country, they return to the place from whence they came. The fertility of the earth is owing to God, "*who watereth the hills from his chambers.*" Hence all the glory and beauty of the vegetable world; hence the grass that nourisheth the cattle, that they may nourish the human race; hence the green herb for food and medicine; hence fields covered with corn for the support of life; hence vine and olive trees laden with fruits, whose juices exhilarate the heart, and brighten the countenance.

They who in old times paid their devotions to the elements, imagined those elements to be capable of giving or withholding rain at pleasure. Therefore, we find, the prophet *Jeremiah* reclaiming that power to *JEHOVAH*, as the God who made and governed the world. "Are there any among the vanities of the gentiles that can cause rain? Or can the heavens give showers? Art not thou he, O *JEHOVAH*, our God? Therefore we will wait upon thee: for thou hast made all these things." Among the Greeks and Romans, we meet with a *Jupiter* possessed of the thunder and the lightning, and an *Æolus* ruling over the winds; but divine
revelation

revelation teaches us to restore the celestial artillery to it's rightful owner. JEHOVAH, the GOD of Israel, the CREATOR of the universe, the REDEEMER of mankind, contrived the wonderful machinery of light and air, by which vapours are raised from the earth, compacted into clouds, and distilled into rain. At his command the winds are suddenly in motion, and suddenly at rest again. We hear the sound, but cannot tell whence they come, or whither they go. *

Be particularly careful then that you never term any effect *natural*, with the intention to deny thereby that it is *divine*, or to exclude GOD entirely out of it; for the GREAT ARCHITECT necessarily presides over and directs every wheel of his machine. It is HE that clothes the grafs of the field, and sendeth the spring into the rivers. It is HE that gives corn, and wine, and oil. It is HE also that sends famine, sword, and pestilence. One time an epidemic distemper raged; 2 Sam. xxiv. 17; and that we might not hereafter on such occasions look alone to the noxious qualities in the air, &c. the veil was for once drawn aside, and presented to open view the destroying angel of the Most High.

Nor let the pert reasoner flatter himself that this is a system only for those who believe the bible. It is impossible to conceive any religion at all, even exclusive of revelation; that is, in other words, to conceive any *trust*, *resignation*, *repentance*, or *gratitude*, towards the Deity, adapted to the successive scenes of human life, upon any other foundation. No independence can be ascribed to the creature; even the sun, the most glorious instrument of created power, visible in the universe, from his first glorious appearance to this good day, never shed one ray of light by any intrinsic power, or inherent virtue of his own.

The

* Dr. Horne, bishop of Norwich, on the Psalms.

The *source of life, beauty, and perfection*, is too often unperceived by the mere naturalist. But he, whose eye is opened and illuminated by truth, sees, contemplates, and adores the AUTHOR AND UNIVERSAL PRINCIPLE OF LIFE; and finds HIM perpetually manifesting HIMSELF in every object of nature, according to it's capacity or aptitude to receive HIS enlivening beams. Separated from *his life-giving energy*, the whole creation of beings, material as well as intellectual, must remain in a state of death. Nought but HIS animating breath can call them forth into life, and array them with robes of beauty.

LECTURE XIV.

ON THE METHOD OF REASONING IN NATURAL PHILOSOPHY.

IN the propofals for thefe Lectures, I engaged to point out to you the true method of reasoning in philofophy, that you might be enabled to diftinguifh what is found and folid therein, from what is hollow and vain. This cannot, I think, be done more effectually than by introducing you to the writings of LORD BACON, whofe plan for the improvement of knowledge comprehends the whole compafs of nature. He may be confidered as the great reftorer of true learning, and the founder of *experimental philofophy*; having done more towards detecting the fources of former errors and prejudices, and towards eftablifhing a true method of philofophifing, than was effected by all the philofophers of the preceding ages.

He has given us an *organum* of a different origin and conftruction from that of *Aristotle*; one which, inftead of *puzzling* all learning with artificial forms, and *perplexing* all knowledge with difputation, puts *truth* and *nature* to the torture by a thoufand trials, and forces them to confefs thofe fecrets, which in fpite of *fyllogifm* had hitherto lain concealed, and by the difcovery of which arts and fciences have been advanced, to the great honour of learning and advantage of fociety.

Two circumftances add greatly to the merit of LORD BACON. The firft is, that at the time his work was written, the world had feen no model of inductive reasoning, from which it's rules might be deduced with amplitude and precifion. *Poets* and *orators* had brought their arts to perfection, ere they

quired wealth, the strength and splendor of his own stock, shining forth unimpaired and unrivalled, lending a lustre to the authority he produces, his depth, his strength, his dignity, and majesty, set him up above every lettered name.

With a capacity of more than ordinary size, a giant in the intellectual world, he breaks through the chains with which authority or tradition had fettered the human mind, subdues the errors formed and fostered by superstition and ignorance, passes the columns fixed as the boundaries of human knowledge, and opens new tracts of light and regions of truth, that were before thought incapable of culture or profit; intent as it were upon nothing but truth, or in his own noble language, "vanquished with the immortal love of truth." While he detects and proscribes vulgar errors, he commits no outrage upon the ancient occupiers, nor offers any gross insult upon the common sentiments of mankind. Nor have we, says he, set off ourselves with glory to draw a majesty upon our inventions, either by triumphs of confutation, or depositions of antiquity, an usurpation of authority, or the veil of obscurity. Thus with a superiority without the pride of genius, we need not wonder, that, humble as the humblest child of faith, he disavows whatever does impair or intrench upon sacred truth, and addresses the LORD for assistance and illumination in his arduous undertaking.*

The end of natural philosophy is to increase either the knowledge or power of man, and enable him to understand the ways and procedure of nature. By discovering the laws of nature, he acquires knowledge, and obtains power; for when these

* Hunter's Sketch of Lord Bolingbroke.

these laws are discovered, he can use them as rules of practice, to equal, subdue, or even excel nature by art. Upon the discovery of these laws, depends the perfection of philosophy, and the enlargement of human knowledge and power.

For this great end *Lord Bacon* exhibits a more perfect method of employing the rational faculty than mankind had been accustomed to; and shews them in what manner they may exalt and improve the understanding, conquer the difficulties, and remove the obscurities of nature. The first part of his *NOVUM ORGANUM*, which may be called *a grammar of the language of nature*, is designed to prepare and purify the mind, that it may be fit to receive the instructions, and use the instruments laid down in the second part.

The human mind, like a mirror, must be smoothed and polished, freed from false imaginations and perverted notions, before it is fit to receive and reflect the *light of truth*, and just information. You may therefore, with the Pythagoreans, lay it down as a maxim, that human advancements should be preceded by, or accompanied with, a suitable degree of purification; for as the diseased eye endures not, till it be restored to health, the view of bright objects, so neither can the mind, without due purification, steadily contemplate the beauty and splendor of truth.

We must therefore, in the pursuit of truth, divest ourselves of all the *IDOLS* or false notions that possess the mind. To every *bias* of the understanding, by which a man may be misled in judging, or be drawn into error, *Lord Bacon* gives the name of *idol*; a word that justly characterises false science; for erroneous knowledge is a species of idolatry, a worship paid to false gods, which is only due to the true one.

All falsehood is opposite to truth. Error is that falsehood, which availing itself either of the weakness of the *understanding*, the depravity of the *will*, or the undue influence of the *imagination*, assumes the *appearance* of truth. Truth is the health, error the disorder of the mind. By purifying the mind from error, you will become a fit receptacle for *divine truth*; by purifying your hearts, you will be conjoined to *divine goodness*, and will enjoy the happiness resulting from so exalted a conjunction.

The *idols* of the mind are either acquired or natural, proceeding from the doctrines and opinions of men, the perverted and corrupt laws and methods of demonstration, or else are inherent in the very constitution of the mind itself. Your first labour should therefore be to liberate the mind from false theories; the next should be to release it from the slavery of perverted demonstrations; and the last to put a check upon its own seductive powers, and either pluck out the inherent idols, or so to watch over them that the depravities they occasion may be corrected. It is a long time before we can be brought to see any thing amiss in the way we have been used to; and even when we do, it is not easy to change what is wrong. Where there is a chain of *prejudice* or wrong *bias* on the understanding, it will neither perceive clearly, nor adhere firmly, to the truth; it will confound things that are different, and obscure things that are clear. The task is difficult, but the reward is great.

It is therefore incumbent on every philosopher to cultivate a disposition of mind, which will make him open to conviction, and ready to acknowledge and rectify mistakes. An obstinate adherence to error generally arises from self-conceit, or a bigotted attachment to a system. True wisdom is ever accompanied with diffidence and humility.

Lord

Lord Bacon divides the unfavourable prepossessions of the mind into four classes; the IDOLS OF THE TRIBE, IDOLS OF THE DEN, IDOLS OF THE MARKET, IDOLS OF THE THEATRE.*

The *idols of the tribe* are those which are common to all men, such as beset the whole species; they arise from the principles of the human constitution, and may have their uses in the present state of human nature; but by excess, or defect, or wrong direction, lead us into much error. The human understanding resembles a mirror of an irregular surface, which mixing it's own nature with the nature of things, distorts and perverts them. Philosophers should always endeavour to conceive things as forming part of the universe, and as having their appropriate office and use therein; whereas they are too apt to consider them only as they have some particular relation to the *senses*, a way by which you will never discover their systematical or cosmical use and qualities.

The *idols* common to human nature are so numerous, that a few only of them can be considered in this place: of these the first is *authority*,† by which men are prone to be led too much in their opinions.

It affixes, as it were, the seal of infallibility on these opinions, it bars the door of science, and in a measure destroys the hopes of posterity. We ought ever to press forward, nor ever conceive that the labours of one man can have set limits to human knowledge, or hearken to those, who, having erected an idolatrous temple to his fame, would have us stop and worship, nor presume to pass the boundaries they have marked for human reason.‡

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* *Idola tribus, idola specus, idola fori, idola theatri.*

† Reid on the Intellectual Powers of the Mind, p. 653.

‡ Young's Essay on the Powers and Mechanism of Nature, preface.

There never was more necessity than at present to point out the dangers arising from the influence of authority, as you will find some philosophers * requiring an implicit faith in the opinions they have adopted; not considering that while our knowledge remains imperfect, our opinions must be mingled with error. It is from this implicit trust upon the credit and blind errors of others, that spring all those *vulgar errors* cherished from age to age by the blindness of prejudice and inveteracy of habit.

In all matters within our cognisance, every man must be determined by his own final judgment, otherwise he does not act the part of a rational being. Authority may add weight to one scale, but man holds the ballance and judges what weight he ought to allow to authority. No claim can deprive us of this right, or excuse us for neglecting to exercise it. *Authority*, however, has it's use; in the first part of life we have no other guide, and without a disposition to receive implicitly what we are taught, we should be incapable of instruction, and incapable of improvement. Even when judgment is ripe, there are many things in which we are incompetent judges. In such matters it is most reasonable to rely upon the authority of those, whom we believe to be competent and disinterested. In matters that we have access to know, authority always will have, and ought to have, more or less weight in proportion to the evidence on which
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* The following paragraphs are specimens among many of the undue influence given to names.

“ Sir Isaac Newton is the person to whom we owe these obligations, and who is henceforth to be considered *as our only sure guide and instructor.*” Again, “ Newton has discovered the chaos, and separated the light from the darkness; his inimitable work, the *Mathematical Principles of Natural Philosophy*, contains the *true astronomical faith*; and those who reject it's doctrines, are the worst of heretics, as they shut their eyes against the clearest of all light, demonstration.”

our judgment rests, and the opinion we have of the judgment and candour of those who differ from or agree with us. Our respect for authority may therefore be too great, or too small. The modest man, conscious of his own fallibility in judging, is in danger of yielding too much to authority; the arrogant, of giving too little.

2dly. The mind is apt to form imaginary relations, and to suppose a greater regularity and uniformity among things than what really exists. Our natural impatience is continually leading us to refer all events to certain general laws, and prevents our following the slow, but sure method of investigation. And though many things in nature are in some measure singular, or extremely dissimilar, the mind is feigning parallels, correspondencies, and imaginary analogies, which have no existence. Arguments from analogy readily present themselves to a warm imagination, while those that are deduced from experiment and observation require strong exertions of the mind, and cannot be formed without attention and application.

In the same manner we are apt to conceive a greater simplicity in nature, than there really is. To love simplicity, and to be pleased with it wherever we find it, is no imperfection, but the contrary. There is without doubt in every part of creation all the beautiful simplicity which is consistent with the end for which it was made. The more we know, the more we discover the uniformity and simplicity in nature, when compared with the vast extent and variety of operations therein. But if we hope to discover how nature brings about it's ends merely from this principle, that it operates in the simplest and best way, we deceive ourselves, and forget that the wisdom operating in nature is more above the wisdom of man, than man's wisdom is above that of a child. It is

indeed a maxim in philosophy, we must not impute to many causes what can be effected by one; this principle is no doubt right, but how are we to judge what is simple, or what is œconomical in nature? only by endeavouring to discover every thing that is necessary to the production of this effect, and must use in our explanation every cause thus discovered, whether they be many or few.

It was believed for many ages, that all the variety of concrete bodies we find on this globe is reducible to four elements, of which they are compounded, and into which they may be resolved. It was the simplicity of this theory, not any evidence from fact, that made it so generally received; for the more it is examined, we find less ground to believe it.

When a real cause is discovered, the same love of simplicity leads men to attribute to it effects which are beyond it's province. A medicine that is found to be of great use in one distemper, commonly has it's virtues multiplied till it becomes a panacea. In other branches of knowledge the same thing often happens. When our attention is turned to any particular cause capable of producing remarkable effects, there is great danger of extending it's influence, upon slight evidence, to things with which it has no connection.

We are in the dark with regard to the real causes of the greater part of the phenomena of nature, and have, at the same time, an avidity to know them; hence ingenious men frame conjectures, which those of weaker understandings take for truth. The fare is coarse, but appetite makes it go down.

3dly. The mind, when it is once pleased with certain things, has a natural tendency to draw all others to consent and go along with them; and though the number of instances that make for the
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the contrary is greater, yet it either does not attend to, or despises them, often rejecting them by some frivolous distinction, pointed out by a strong and pernicious prejudice, in order to maintain the authority of it's first choice unviolated. *Diagoras*, on being shewed in the temple of Neptune many *votive pictures*, of such as had escaped shipwreck, was asked by his guide whether he did not acknowledge the divine power? wisely answered, *Shew me, first, where those are painted that were shipwrecked after having thus paid their vows?* Hence also in most cases of superstition, as of astrology, dreams, judgments, &c. those who find pleasure in such kind of vanities, always observe where the event answers, but slight and pass by the more frequent instances where it fails. The imagination is so captivated, that the powers of reason are incapable of freeing it from the enchantment. This mischief diffuses itself still more subtilly in philosophy and the sciences, where that which has once pleased infects and subdues all other things, though much more substantial and valuable than itself. The mind is always also more moved and excited by affirmatives than by negatives, whereas it should duly and equally yield to both. In raising of true *axioms*, negative instances have the greatest force.*

4thly. The human intellect is most moved and captivated by those things that strike and enter it at once, filling and swelling the imagination; but for the rest, it feigns and supposes them in an imperceptible manner to be like those few that possess the mind. We have a general disposition to measure things less known and familiar by those that are better known and more familiar: whereas the understanding is slow, and unwilling to pass

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See this fully shewn in Nov. Org. part ii. sect. ii.

to remote and dissimilar instances, whereby axioms are tried as it were by the fire.

This natural proneness to judge of things less known by those that are familiar and better known, must not, however, be altogether laid aside, as it is the foundation of all analogical reasoning, to which we are indebted for a great part of our knowledge. It is difficult, however, to judge how far we may venture upon it. The objects of sense engross our thoughts in the first part of life, and are most familiar through the whole of it. Hence in all ages men have been prone to give human passions, frailties, &c. to superior intelligences. Hence the disposition in men to materialize every thing, and to apply their notions of material objects to things of another nature. Hence the many crude and ill-digested theories on our ideas.* The mistakes in common life, which are owing to this propensity, are innumerable. Hence the selfish man thinks all pretences to benevolence and public spirit to be mere hypocrisy, and self-deceit: while the generous and open-hearted easily believe fair pretences, and consider men as better than they really are.

5thly. Another idol of this tribe has its origin in the natural restlessness of the human understanding, always moving, but far too often to no purpose, as when it is in search of things beyond its reach. There is not a greater source of error than in the misapplication of our noblest intellectual power to purposes for which it is incompetent.

The works of men, and the works of God, are not of the same order. The force of genius may enable a man perfectly to comprehend the former. What is contrived and executed by one man, may be perfectly understood by another. He may
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* See Reid's Essay on the Intellectual Powers of Man, p. 654.

from a part conjecture the whole, or from effects may conjecture the causes, because they are the effects of a wisdom not superior to his own.*

But the works of creation are contrived and executed by a power and wisdom infinitely superior to that of man. And when men attempt, by the force of genius, to discover the causes of the phenomena in nature, they have only a chance of going wrong more ingeniously. Their conjectures may appear very probable to beings no wiser than themselves; but they have no chance to hit the truth. They are like the conjectures of a child, how a ship of war is built, and how it is managed at sea. It gratifies the pride and natural propensity of the human understanding; but it is an attempt beyond our force, like that of *Phaeton*, to guide the chariot of the sun.

Full liberty must be allowed to our inquiry, that natural philosophy may acquire all the certainty and perfection of which it is capable; but we must not abuse this liberty by *supposing*, instead of *inquiring*, by framing systems, instead of deducing the constitution of things from observation and experience. An attachment to systems prevents us from attending to the real state of things, or makes us reject them, or interweave therewith our own conceits.

Systems and hypotheses in general, framed by philosophers out of their own ideas, and separated by the mind from the truth of things, were the bane of natural philosophy, and for centuries opposed the advancement of science.

In all inquiries into the constitution of nature, human genius may combine, but it must not fabricate. It may collect evidence, but it must not supply the want of it by conjecture. It may display

* Ibid. p. 669. Maclaurin's Account of Sir Isaac Newton's Discoveries, p. 7. See also Lecture ii. p. 59.

display it's powers, by putting nature to the question by well-contrived experiments; but it must add nothing to her answers.

6thly. Another impediment and deviation of the understanding arises from the dullness, incompetency, and fallacies of the senses. Hence the things that strike the sense, unjustly overballance those that do not strike it immediately. So that contemplation usually ends with sight, and little or no observation is made of things INVISIBLE. Hence all the operations of the different airs included in tangible bodies, all subtil organizations, and the motion of the parts, are unknown to mankind; yet *unless they are discovered and brought to light*, no great progress can be made in the knowledge of nature; *for it is by subtil matters in motion that her chief operations are performed*. Nor can instruments for improving and sharpening the senses be here of any great service; for all true *interpretations* of nature are made by apposite *instances* and experiment, *where sense judges of the experiment only, and the experiment judges of nature and the fact*.

Idols of the den. These are prejudices that take their rise, not from the constitution of human nature, but from something peculiar to every individual, from education, custom, and a variety of other circumstances. Our excellent logician, Lord Bacon, seems to have taken this appellation from *Plato's* beautiful emblem of the *cave*; for if any one should, in his infancy, be educated in a dark cave, remaining there till he was of full age, and should then of a sudden be brought into broad daylight, and behold the apparatus of heaven and earth, no doubt many strange and absurd thoughts would arise in his mind. And though we live, indeed, in the view of heaven, our minds are confined in the caverns of our bodies, where we
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receive infinite images of error and falsehood, if we do not constantly dwell in the contemplation of nature, as it were, in the open day-light. This emblem of *Plato* agrees well with the saying of *Heraclitus*, *That men seek the sciences in their own narrow world, not in the wide one.* Further, as in a cave objects vary their appearance according to the form of the cave, and it's manner of receiving the light; so *Lord Bacon* conceives the mind of every man to resemble a cave, which has it's particular form and particular manner of being enlightened, and which from these circumstances often gives false colours, and a delusive appearance to objects seen in it.

Hence the perversion and misapplication of reason, and the abuse of learning, become the source of many errors. Under this head you may reckon the reasoning from *no principles at all*; the reasoning from the principles of one branch of learning in the method of another; the reasoning from the principles of one to the truths of another; or lastly, the expecting the same kind and degree of conviction in the truths of one, which belong to another, and which it does not admit. These four causes arising from the abuse of learning will account for many scientific errors. However various the errors of the learned may appear to be, they all originate either in the *pride* or *prejudice* of the human mind; for according to the observation of *Lord Bacon*, of opposite errors, the causes of erring are commonly the same.

Though it may appear absurd that any one should reason from no principle at all, yet is it an error of great and extensive influence. Great are the powers of the human mind, but her *presumption* is still greater. Not content to be employed upon such principles and materials as are provided for her use by *Providence*, and the natural state of things,

things, in a slow and sober exercise, vainly presuming, by an action and operation of her own, to invent others of a superior order, by whose assistance she may soar with a rapid wing into the possession of the sublimest truths; buoyed up into the air by these self-inventions, she attempts unbounded flights into the fertile but delusive regions of imagination. Hence we often see philosophers led by trains of solid reasoning to the temple of splendid and delusive errors.

The other three causes just enumerated have their origin in *prejudice* arising from partial and inveterate *habits*. Man is altogether the creature of *habit*; all his virtues are habits; all his vices are habits; habit has its sway also over his mind both in the elegant and scientific parts of learning.

As the ear is prepared and qualified by habit for the enjoyment of music, the eye for that of painting, and every other part of the mental and corporeal frame adapted to its proper object; so is the mind prepared and qualified by habit for the search and relish of every kind of truth.

But this same habit, which is the friend to all knowledge, by being too long and too closely confined to the same object, employments, and pursuits, generates a prejudice, and confirms a partiality which generally cramps and confines, and often weakens and destroys the powers of the mind. Being addicted to one set of principles, habituated to one train of reasoning, and accustomed to one species of conclusions, they are disqualified by the very habits of stating, reasoning, and concluding, and by their very success in some parts of learning, from prosecuting truth in others.*

Men are fond of particular sciences and studies, either when they believe themselves the
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* Tatham's Scale and Chart of Truth, vol. ii. p. 304.

authors or inventors thereof, or because they have bestowed much pains upon them, or applied themselves thereto. A man whose thoughts have been confined to a certain track by his profession, or manner of life, is very apt to judge wrong when he ventures out of that track. He is apt to draw every thing within the sphere of his profession, to wrest and corrupt every new contemplation with his habitual idea, and to judge of things by maxims which have no relation to them.

Aristotle furnishes us with a signal example of the foregoing observations; he made his natural philosophy such a slave to his *logic*, as to render it contentious, and in a great manner useless. The mere *mathematician* is apt to apply measure and calculation to things incapable of being measured: direct and inverse ratios have been applied to measure human affections, and the moral worth of actions. An eminent mathematician attempted to ascertain, by calculation, the ratio in which the evidence of facts must decrease in the course of time, and fixed the period when the evidence of the facts, on which christianity is founded, shall become evanescent; and when in consequence no faith shall be found on the earth. The ancient *chemists* were wont to explain all the mysteries of nature, and even of religion, by salt, sulphur, and mercury.

The great and radical difference of capacities as to philosophy and the sciences, lies, says our noble author, in this; that some are stronger and fitter to observe the differences of things, others to observe their correspondences. A steady and sharp genius can fix it's contemplations, and dwell and fasten upon all the subtilty of differences. While a sublime genius, with a quick conception, perceives and compares the smallest and most general agreement of things: both kinds easily falling into

excess; the one by grasping at the dividing scale, the other by embracing the shadows of things.

To contemplate nature and bodies in their simplicity, breaks and grinds the understanding; to consider them in their configurations and compositions, blunts and relaxes it. The former is so taken up with the particles of things, as almost to neglect their structure: while the other views the fabrication with so much astonishment, as not to enter into the simplicity of nature. Both these kinds of contemplation should therefore be taken up by turns, that the understanding may at the same time be piercing and capacious, and the above-mentioned inconveniences with the *idols* thence arising may be prevented.

Different persons, either from temper or education, have different tendencies of understanding, which by their excess are very unfavourable to sound judgment. Some men of genius are wrapped up in the admiration of antiquity, and contempt of whatever is modern; others go as far into the contrary extreme, and are delighted only with what is novel. Some either quarrel with what was justly laid down by the ancients, or despise what is justly advanced by the moderns. The unballanced mind of man is alwas shifting from one excess into another, and rarely knows to sustain itself in that just *mean* which right reason and pure religion demand. It is inconceivable to those who are only acquainted with the present state of the learned world, to what an absurd height this attachment to antiquity was formerly carried. Both extremes are highly prejudicial to philosophy and the sciences, as being rather an affectation of *antiquity* and *novelty*, than any true judgment. For truth is not to be derived from any felicity of *times*, which is an uncertain thing, but from the light of nature and experience, which is eternal. These affectations

are therefore to be laid aside, and care be taken that the understanding be not hurried away with them.

Let *contemplative prudence*, says our incomparable author, proceed in chasing and dislodging the *idols of the den*, and learn to suspect whatever powerfully strikes and detains the mind, using then greater caution to preserve your understanding pure and equable.

A spirit of prejudice and prepossession is very detrimental to philosophy, it admits of no improvement but what it brings from it's own fund. When a man has strongly imbibed any particular notions, he investigates nature not to receive information, but to find support for his own opinions.

A love of novelty is also very injurious to real truth; the knowledge of any truth apprehended as useful to mankind, is pleasing to the mind, and our eagerness to enjoy this pleasure makes us often entertain a persuasion of knowing a thing before we really do, or upon a very weak ground. It is therefore dangerous to pass a judgment upon a new discovery while it is new; we should wait until time has abated the sweetness of novelty, and given scope for reflection to flow in from different quarters. The proper spirit for investigation, is humility, sobriety, calm consideration, attentive industry, and perseverance.

Lord Bacon shews, that of various prejudices, there are none so troublesome as the *idols of the market*, which insinuate themselves into the mind from the association of words and terms, the imperfections and the abuse of language. Language can reach no further than our notions; and if these be vague and ill-defined, the words by which we express them must be so likewise. A stronger instance of the abuse of words can scarce be found than in the nomenclature of the French chemists,

designed to prepare the mind for slavery by "babbling a dialect of France." For though men believe, says Lord Bacon, their reason governs words; it also happens, that words retort and reflect their force upon the understanding; whence philosophy and the sciences have been rendered sophistical and inactive. Words are generally imposed according to vulgar conceptions, and divide things by lines, i. e. distinctions or differences, that are most apparent to the understanding of the multitude: and when a more acute understanding, or a more careful observation, would remove these lines, to place them according to nature, words cry out, and forbid the alteration. Hence it happens that serious disputes frequently terminate in controversies about words and terms, which it were better to reduce to order by definitions. But in natural and material things, even these definitions cannot remedy the evil, because definitions themselves consist of words, and words generate words; so that of necessity recourse must be had to particular *instances*, their *series* and *orders*.

The fourth kind of prejudices mentioned by our author are the *idols of the theatre*, which are neither constitutional nor secretly insinuated into the understanding, but palmed upon it, received from fabulous theories and perverted demonstrations, arising from the systems or sects in which we have been trained, or which we have adopted. A false system once fixed in the mind, becomes as it were the medium through which we see objects; they receive a tincture from it, and appear of a different colour from what they do when viewed by the pure light.

In Lord Bacon's method of studying philosophy there is no necessity for confuting the various theories; yet that the passage to truth may be made easier, and the understanding the more disposed to cleanse

cleanse itself, and put away it's idols, without which true philosophy can never be effectually promoted, (for the sciences formed by distempered minds will partake of their distempers,) he has classed some of the more ancient kind, and given some account of them. He classes them all under three heads: 1st. The Sophistical: 2d. Empirical: and 3d. Superstitious.

The first are the *sophistical*, who hastily take up vulgar things from experience, without ascertaining their certainty, or carefully examining and weighing them, committing all the rest of the work to thought and the discussion of the wit: these he compares to spiders, who form their webs from their own bowels to catch unwary insects in their aerial flights. Common observation and obvious experiments are not of themselves sufficient for the foundation of a serviceable philosophy; nor is the common logic an engine at all suited to deal with experiments, observation, and nature. Of these we have an eminent example in *Aristotle*, who corrupted *natural philosophy* with his *logic*. He seemed to be more solicitous how men might defend themselves by answers, and advance something that should be positive in words, than to come at the inward truth of nature; and where he had experience for his guide, to wind her round, and lead her captive to his opinions. Now as the education of the great schools is chiefly *Aristotelian*, we should have a strict watch upon ourselves in all philosophical inquiries, writings, and discourses, that we are not led away with Aristotelian notions. All our common reasoning seems infected with Aristotelian prejudices, so as to be affectedly logical and captious, rather than just and philosophical, or formed upon the true nature of things.

The *empirical* philosophers are those, who labour with great diligence and accuracy, in a few

experiments; and then venture to deduce theories and build up systems, strangely wresting every thing else to these experiments. Bacon compares them to insects gathering up grain, and laying it by as they found it. The opinions produced by these are more deformed and monstrous than those of the sophistical kind, as not being founded in the light of vulgar notions (which are in some degree general and universal); but rest in the narrow confines and obscurities of a few experiments: whence such a philosophy appears probable, and in a manner certain, to the men who daily converse with these experiments, and thereby deprave their imagination; whilst to others the theories appear incredible and vain. Of this you will find examples in most of the ancient chemical writers, in Gilbert's magnetical philosophy, and that of many moderns, some of whom resolve all difficulties by attraction, others by repulsion, &c. You can never use too great caution on this head, for the understanding is always eager, and precipitated by it's desire of bounding or flying to general and first principles; thus forming theories on very feeble ground. The infinite variety of natural objects, the stupendous coincidence by which all agree and all differ, must convince you, that no vigour of judgment, or warmth of fancy, is equal to the tracing of every phenomenon to it's first principles, or forming an hypothesis adequate to explaining all the operations in nature.

There is also danger from *superstition* and *theology* (though much less so than heretofore); for the understanding is as subject to the impressions of fancy as those of vulgar notions: by the former it is flattered and courted, and therefore deceived. We meet with this in all theories, where first and final causes are introduced, and the intermediate ones omitted. We should be careful in this case that

we be not led thereby to canonize error, and venerate vanities. Some modern writers have so far indulged this strange levity, as to endeavour the founding of natural philosophy upon the first chapter of Genesis, and other parts of sacred writ; thus *seeking the dead among the living.*

The true philosopher, Lord Bacon compares to the bee, that gathers the matters from the flowers of the field, from which with admirable skill she makes her honey. He neither trusts wholly to his own understanding, nor contents himself with recording the history of mechanical experiments; but by reasoning skilfully from them brings forth truth and science, the great and noble production of the human faculties.

He very properly reprehends those, who, upon a weak conceit of sobriety, or ill-applied moderation, thought or maintained that a man can search too far, or be too well studied in the *book of God's word*, or in *the book of God's works*; but rather he says, let men awake themselves, and chearfully endeavour to pursue an endless progress and proficiency in both; only let them beware, lest they apply knowledge to pride instead of charity, to ostentation instead of use. He also observes, that in the entrance of philosophy, when the second causes, most obvious to the senses, offer themselves to the mind, we are apt to cleave unto and dwell too much upon them, so as to forget what is superior thereto: but when we pass further, and behold the dependence, continuance, and confederacy of causes, and the works of providence; then, according to the allegory of the poets, we easily believe that the highest link of nature's chain must needs be tied to the foot of Jupiter's chair, or perceive that philosophy, like *Jacob's vision*, discovers to us a ladder, whose top reaches up to the footstool of the throne of God.

False schemes of natural philosophy may lead to atheism, or suggest opinions concerning the Deity, and the universe, of the most dangerous consequences to mankind: and you have the more reason to be on your guard on this head, as the philosophers of France have, for many years, been perverting it to the most dire and malignant purposes. True philosophy will lead you to believe in, and adore, the Supreme Being; and as it continually exhibits brighter and brighter instances of his wisdom and power, it removes also, in part, that veil spread over nature, which conceals from our view it's awful depths and majestic heights; and thus enables you to see the glories of the Almighty shining in this HIS exalted creation, and hence instructs you to raise your voice in praises to HIM, who is alone worthy to receive glory and honour and power; for it is by *Him* that all things were created, and it is by *Him* that they are continually preserved.

“ That ONE *great and universal* MIND, who made all things by his power, and preserves them in his goodness, is the first and only cause, operating at all times and in all places, and producing, by an exertion of his will, all the various phenomena of the material system. This first and universal cause, however, in the ordinary administration of his providence, hath condescended to employ *second causes* as the instruments of his will, by which he acts; which second causes HE hath also appointed in his wisdom to operate through every part of his creation by *general laws*. To trace the hand of the ALMIGHTY through all his works, to investigate these *general causes*, and to erect them into the *laws of physics*, is the sublime, the delectable, and honourable employment of the natural philosopher.” *

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* See Tatham's admirable work, entitled, *Scale and Chart of Truth*, p. 133.

To explain, therefore, with certainty the phenomena of nature, to remove their obscurities, and observe their influence and connection, is the great business of philosophy; for this purpose the observer must obtain certain fixed points, which may serve as signals to conduct him in the difficult path he has undertaken, and prevent his wandering too far from the main road.

Physical logic does not consist in argument, but in discovering facts, not what agrees with principles, but the principles themselves. There is a meaning and design in every operation of nature. The natural philosopher endeavours to discover this meaning, and interpret these designs by a careful observation of her steps; but if the mind hastily imbibes, and without discrimination treasures up the first notices of things, error will ever prevail and remain uncorrected; for if these primary notices are vitiated, confused, or inaccurate, those derived from them will be equally defective, and the knowledge built thereon like a magnificent structure on a bad foundation.

The philosopher, therefore, avoids the demonstration of *syllogism*, because it continually lets nature and reality slip through it's fingers, and wrests the works thereof to make them square with the works of men; whereas the works of men ought to be submitted and formed according to the works of nature; so that *logical* demonstrations applied to physical matters are only the play of words. He therefore takes *induction* for the form of demonstration, as it guards the senses, presses nature close, and rules over her works.

Instead of flying immediately from the senses, and particulars to generals, (about which disputes always turned) and deriving intermediate principles from these in a short but precipitate manner, a manner fit for controversy, but unfit to close
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with nature, he endeavours to raise propositions by degrees, and thus arrive at *general axioms*, axioms not notional, but well defined, and such as are conformable to the nature of things.

Axioms raised, says *Lord Bacon*, by argumentation can never be useful in discovering new works; for there is no mode of raising axioms, but by a legitimate and proper form of induction, capable of separating experience, and concluding of necessity after all the proper rejections and exclusions are made.

Beginning then with phenomena, the philosopher endeavours to trace out the proximate causes, and rising gradually from particular causes, he proceeds to the more general, and so on by sure and uninterrupted steps, man comes without stop or gap to the top round, or unity of nature; from whence he may descend in a contrary order, and from established principles explain the phenomena derived from them. In no other mode can we be sure that we assume the principles which really obtain in nature, or that any system we may compose, is not mere dream and illusion.

Thus you see that the process of *induction* is an ascent from particular premises to general conclusion. The evidence of such general conclusion is only *probable*, not *demonstrative*; yet if the induction be sufficiently copious and properly conducted, it forces conviction as strongly as demonstration.

Mere reasoning will carry a man but a very little way in most subjects; but by observation and experiments properly conducted, the stock of human knowledge may be continually enlarged.

Before the philosopher forms his judgment, he must, by accurate experiments, and diligent observations, search out how far the phenomenon he is investigating is influenced by others, and
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this in all possible cases and circumstances, by what modifications it is affected, and in what proportion it is combined and connected with other effects: he will thus endeavour to obtain an exact notion of the object of his researches, and marching solidly towards truth, he will interrogate nature with success; being careful to stop where no experimental proof can be procured, and not presuming where the subtilty of nature carries things out of his reach; for he might as well pretend to build without materials, as to form without observation and experiment a rational system of natural science.

General principles cannot be established with solidity, without numerous experiments, and many observations on the same individual subject, and then on different subjects of the same species: their probability is greater as the observations on which they are founded are more numerous, and accurately performed: all exceptions being then made, a sound and serviceable portion of truth will be left behind as a *general axiom*. "By a repetition of the same industrious process and laborious investigation, he advances from general to more general, till at last he is able to form a few of the most general, with their attributes and operations, into *axioms, or secondary principles*, which are the well-founded *laws* enacted and enforced by the God of nature."

Having discovered any of these laws or causes, it becomes the business of philosophy to trace them in all their effects, and to predict similar appearances from similar previous situations. The philosopher, by knowing what will be the result of putting things into a variety of circumstances, becomes master of the powers of nature, and can apply them to useful purposes of life; and thus

thus does knowledge, as Lord Bacon observes, become *power*.

The ancient logic, far from correcting what was wrong, served rather to fix error in the mind than open the way to truth. LORD BACON had to begin anew, and lay down such rules for the workings of the mind, as would never leave it to itself; as if the business was to be performed by a machine (an organum), which would settle the degrees of certainty, and contrive such ways of submitting things to the senses, as that a true judgment might be formed concerning them. Being convinced by careful observation, that the *human understanding* perplexes itself, and does not make a sober and advantageous use of the real helps within it's reach; and that this occasioned manifold ignorance and many inconveniences; he employed his utmost endeavours to restore and cultivate a just and legitimate familiarity between the mind and things, by raising a new *art*, in which *reason* and *experience* should be joined together for the improvement of philosophy. This establishment of a new logic is called, by our author, *the art of interpreting nature*.

The end of the new logic is, as we before observed, to find not *arguments* but *arts*; not what agrees with principle, but principles themselves; not probable reasons, but *plans* and *designs* of works; a different intention produces a different effect. In one the adversary is conquered by *dispute*, in the other nature by works. And suitable to this difference of the design, is the nature and order of the demonstrations, which here is purely inductive. Those therefore who determine not to conjecture, but to find out and know, not to invent *fables* and *romances of worlds*, but to look into and dissect the nature of this *real world*, must only consult things themselves. Nor can any force of
genius,

genius, stretch of thought, or subtilty of argument, be substituted for labour, search, and inspection.

The knowledge and power of man are coincident ; for while he is ignorant of causes, he can produce no effects. Nature is only to be conquered by submission, by condescending to inquire into and observing her methods of working, as a servant would learn those of his master. No power of man can break the natural chain of causes ; so that the only method whereby man can *rule* nature, must depend upon learning her ways. And good hopes can only then be conceived of the science, when by continued steps, *like real stairs uninterrupted or unbroken*, men shall ascend from particulars to *lesser axioms*, and so on to middle ones, and from these again to higher, and lastly, to the highest of all ; and thus discover the *forms* or *active laws of nature*, by which all things exist and have their effects. To the discovery of these laws we are continually directed by Lord Bacon, as to a thing that alone will constitute a just and universal theory, and direct to an extensive practice. *His Instauration*, or scheme for rebuilding arts and sciences, depends upon the *discovery of forms*. But these forms or *laws* can be truly investigated by no other means than that of *induction*.

It is therefore of the utmost importance in philosophy to ascertain, as accurately as possible, the general powers in nature, to determine their causes, and trace their consequences ; for as the phenomena of nature are infinite, and the faculties of the human mind are limited, these phenomena, when considered as unconnected with other facts, convey but little instruction. The infinite not being the object of science, till the forms or laws of nature be known, by careful observation and accurate induction, no progress can be made in natural philosophy.

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Hence the necessity of collating and connecting corresponding facts, and the advantage of reducing them to certain axioms, and applying these to account for other phenomena; that we may at last advance to a knowledge of the most general laws that regulate the system of operations in nature. But though we may be warranted to consider all the phenomena that we find connected with these general laws, and manifestly depending upon them, as so many facts explained, so many truths known and understood; yet we ought not to overlook such phenomena, as are not reducible to those general principles; but should view them as simple and separate facts, and treasure them up till a more enlarged experience, and more accurate observation lead us to the discovery of those powers of nature to which they are to be referred.

This method of *reasoning* founded on experiments and observation, by which the general ideas and *forms* of natural philosophy are invented, is purely and exclusively *inductive*. The schools are not the theatre in which this philosophical logic is displayed. It does not delight in external appearances and ostentatious formality. It retires from the clamour of verbal disputation into the retreat of the elaboratory and observatory, where in silent investigation it lays the foundation of substantial learning; and as it mixes with experiment and observation, it is incapable of being adequately described by words, but is best seen and understood by attending it in the act, and pursuing it through every stage of the analytical progression.*

After men had laboured in the search of truth near 2000 years by the help of syllogisms, Lord Bacon proposed the method of *induction* as a more effectual engine for that purpose. His *Novum Organum*

* Tatham's Chart and Scale of Truth, p. 137.

ganum gave a new, useful, and remarkable turn to the thoughts and labours of the inquisitive, and may be considered as forming a grand æra in the progress of human reason.*

Neither experience nor experiment must, however, be considered as such infallible guides, as to justify our refusing information from any other quarter: for they never make us thorough masters of the subject. We may know enough for our present uses, but can never know that there is not more to be learnt, besides what we have discovered. We can only observe what effects they work upon our senses, or upon one another, and from thence induce imperfectly the powers belonging to them, and causes operating upon them, but can make no just deduction that there are not other powers and causes whose effects we have never yet experienced.

The greatest part of human knowledge rests upon probable evidence. Indeed we can have no other for general truths, which are contingent in their nature, and depend upon the will and ordination of the maker of the world. He governs the world he has made by general laws. The effects of these laws in particular phenomena, are open to our observation, and by observing a train of uniform effects with due caution, we may at last decypher the law of nature by which they are regulated.

Such is the genuine logic of physical learning, which has before it such a vast extent and variety of ground, as is sufficient to employ the joint and confederated labours of philosophy of different ages and countries, assisted by the largest collection and best arrangement of natural history, which is the proper foundation of natural philosophy. From this ground experience takes its slow but steady course; it first, says Lord Bacon, lights the

* Reid on the Intellectual Powers of the Mind.

the candle, and then by that candle shews the way, beginning with regular and well conducted experiments, not such as are vague and preposterous, from whence it derives axioms; and then from axioms well established descends to new experiments.

“ But however numerous and extensive the experiments and observations may be, they must of necessity come short of the number and extent of nature, which in some cases will defeat all possibility of their coextension, and in others, by its distance, lies out of the reach of their immediate application. In order, therefore, to make his law of general use, and stretch it over the whole extent of nature, the philosopher is obliged to have recourse to *analogy*, by which he can lengthen out his inductions, which are properly confined to the number of experiments and observations actually made, to all others of the same kind; concluding the axiom to hold good of all, and that not only for the present, but also for the future, till it be either confirmed and rectified, or else contradicted by better experiments, and a more extensive and complete induction.” For if in reasoning about natural things, we were confined wholly to experience, our knowledge must fall short of being general, for it would be confined to those alone on which we made our experiments.

“ This is that just and philosophic method of reasoning, which sound logic prescribes in this, as well as in other parts of learning; by which, through the slow but certain road of experiment and observation, the mind ascends from appearances to qualities, from effects to causes; and, by a fair *induction* from many particular subjects extended by *analogy*, forms *general propositions* concerning the powers and properties of physical bodies. What can fairly be deduced from facts duly observed, or

ufficiently attested, is genuine and pure; it is the voice of God, and no fiction of human imagination.

The view of nature, which is the immediate object of sense, is very imperfect, and of a small extent; but by the assistance of art, and the help of our reason, is enlarged till it loses itself in an infinity on either hand. The immensity of things on the one side, and their minuteness on the other, carry them equally out of our reach, and conceal from us the far greater and more noble part of physical operations. As magnitude of every sort, abstractly considered, is capable of being increased to infinity, and is also divisible without end; so we find that, in nature, the limits of the greatest and least dimensions of things are actually placed at an immense distance from each other. We can perceive no bounds of the vast expanse in which natural causes operate, and can fix no border or termination of the universe; and we are equally at a loss when we endeavour to trace things to their elements, and to discover the limits which conclude the subdivisions of matter. The objects which we commonly call great, vanish when we contemplate the vast body of the earth: the terraqueous globe itself is soon lost in the solar system: in some parts it is seen as a distant star: in great part it is unknown, or visible only at rare times to vigilant observers, assisted, perhaps, with an art like to that by which Galileo was enabled to discover so many new parts of the system. The sun itself dwindles into a star; Saturn's vast orbit, and the orbits of all comets, croud into a point, when viewed from numberless places between the earth and the nearest fixed stars. Other suns kindle light to illuminate other systems, where our sun's rays are unperceived; but they also are swallowed up in the

vast expanse. Even all the systems of the stars that sparkle in the clearest sky, must possess a small corner only of that space over which such systems are dispersed, since more stars are discovered in one constellation by the telescope, than the naked eye perceives in the whole heavens. After we have risen so high, and left all definite measures so far behind us, we find ourselves no nearer to a term or limit; for all this is nothing to what may be displayed in the infinite expanse, beyond the remotest stars that ever have been discovered. If we descend in the scale of nature towards the other limit, we find a like gradation from minute objects to others incomparably more subtil, and are led as far below sensible measures as we were before carried above them, by similar steps that soon become hid to us in equal obscurity. We have ground to believe, that these subdivisions of matter have a termination, and that the elementary particles of bodies are solid and uncompounded, so as to undergo no alteration in the various operations of nature or of art. But from microscopical observations that discover animals, thousands of which could scarce form a particle perceptible to the unassisted sense, each of which has it's proper vessels, and fluids circulating in those vessels; from the propagation, nourishment, and growth of those animals; from the subtilty of the effluvia of bodies retaining their particular properties after so prodigious a rarification; from many astonishing experiments of chemists; and especially from the inconceivable minuteness of the particles of light, that find a passage equally in all directions through the pores of transparent bodies, and from the contrary properties of the different sides of the same ray; it appears, that the subdivisions of the particles of bodies descend by a number of steps or degrees that surpasses all

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imagination, and that nature is inexhaustible by us on every side. Nor is it in the magnitude of bodies only that this endless gradation is to be observed. Of motions, some are performed in moments of time, others are finished in very long periods; some are too slow, and others too swift, to be perceptible by us. The tracing the chain of causes is the most noble pursuit of philosophy; but we meet with no cause but what is itself to be considered as an effect, and are able to number but few links of the chain. In every kind of magnitude, there is a degree or sort to which our sense is proportioned, the perception and knowledge of which is of the greatest use to mankind. The same is the ground work of philosophy; for though all sorts and degrees are equally the object of philosophical speculation, yet it is from those which are proportioned to sense that a philosopher must set out in his inquiries, ascending or descending afterwards as his pursuits may require. He does well indeed to take his views from many points of sight, and supply the defects of sense by a well-regulated imagination; nor is he to be confined by any limit in space or time: but as his knowledge of nature is founded on the observation of sensible things, he must begin with these, and must often return to them to examine his progress by them. Here is his secure hold; and as he sets out from thence, so if he likewise trace not often his steps backwards with caution, he will be in hazard of losing his way in the labyrinths of nature.

From this short view of nature, and of the situation of man, considered as a spectator of it's phenomena, and as an inquirer into it's constitution, we may form some judgment of the project of those, who, in composing their systems, begin at the summit of the scale, and then by clear ideas

pretend to descend through all it's steps with great pomp and facility, so as in one view to explain all things. The processes in experimental philosophy are carried on in a different manner; the beginnings are less lofty, but the scheme improves as we arise from particular observations to more general and more just views. It must be owned, indeed, that philosophy would be perfect, if our view of nature, from the common objects of sense to the limits of the universe upwards, and to the elements of things downwards, was complete; and the powers or causes that operate in the whole were known. But if we compare the extent of this scheme with the powers of mankind, we shall be obliged to allow the necessity of taking it in parts, and of proceeding with all the caution and care we are capable of, in inquiring into each part. When we perceive such wonders, as naturalists have discovered, in the minutest objects, shall we pretend to describe so easily the productions of infinite power in space, that is at the same time infinitely extended and infinitely divisible! Surely we may rather imagine, that in the whole there will be matter for the inquiries and perpetual admiration of much more perfect beings.*

It is not, therefore, the business of philosophy, in our present situation in the universe, to attempt to take in at once, in one view, the whole scheme of nature; but to extend, with great care and circumspection, our knowledge by just steps from sensible things, as far as our observations or reasonings from them will carry us, in our inquiries concerning either the greater motions and operations of nature, or her more subtil and hidden works.

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* Maclaurin's Discoveries of Sir Isaac Newton, p. 15.

Among those who have pursued the path pointed out in the *Novum Organum*, Sir ISAAC NEWTON holds the first rank. It was on this plan he established his account of the system of the world upon the best astronomical observations on the one hand; while on the other, he performed himself, with the greatest address, the experiments, by which he was enabled to pry into the secrets of nature.

He has given us two incomparable treatises, his *Mathematical Principles of Philosophy*, and his treatise of *Optics*. In the first, he describes the system of the world, and shews the powers which govern the celestial motions. These are extended from the center of the sun to the utmost altitude of the highest comet. In the second he treats of light, one of the most potent agents in nature.

The first rule of philosophizing laid down by this great man is this: *No more causes, nor any other causes of natural effects, ought to be admitted, but such as are both true, and sufficient for explaining their appearances.* This is a golden rule. If a philosopher, therefore, pretends to shew you the cause of any natural effect, whether relating to matter or mind, consider first, whether there be sufficient evidence that the cause assigned does really exist. If there be not, reject it with disdain, as a fiction, which ought to have no place in genuine philosophy. If the cause assigned really exists, consider in the next place, whether the effect it is brought to explain necessarily follows from it: unless it has these two conditions, it is good for nothing.

The second rule of the great Newton is this: *That natural effects of the same sort are to be accounted*

for by the same causes. This rule is founded on a just appreciation of analogy, on the uniformity of the proceedings in nature. Thus it considers the descent of a heavy body towards the earth in Europe as an effect of the same sort with the descent of a heavy body towards the earth in America. To such effects, therefore, similar causes ought to be assigned. The motion of the moon round the earth, of the satellites round Jupiter or Saturn, and of the primary planets round the sun, are effects of the same kind. Therefore whatever you find to be the cause of one of these motions, you may conclude to be the true cause of the others.

It is easy for you to observe, that this rule is deduced from the latter part of the foregoing one. Effects of the same kind may be accounted for by the same causes. It is right, therefore, to assign the same causes to similar effects; because we should otherwise multiply causes without reason, and should introduce more than are sufficient for the appearances of nature.

Newton's third rule is built upon induction and analogy, and considers *those qualities that are found invariably to belong to all bodies, upon which we can make experiments, as qualities belonging to all bodies whatsoever.*

There are many bodies on which we cannot make experiments; yet if we have frequently made experiments upon other bodies, that fall immediately under our notice, and find them invariably endued with certain qualities, we may be allowed by analogy to extend our conclusion to all other bodies, and thus make it universal: a way of reasoning, that is agreeable to the harmony of things, and to the old maxim, ascribed to *Hermes*, and approved by the observation

observation and judgment of the wisest philosophers, *That what passes in the heavens above is similar and analogous to what passes on the earth below.**

Thus all bodies, that we have observed, are found to gravitate towards one another; they endeavour, if they are near the earth, to descend by their weight to the earth's center. Now though we have not tried the experiment on every stone, or upon every piece of lead that we see, yet from what we have tried, we conclude that all of them have this same quality. And if this conclusion be just, when extended thus far beyond our own observation, we may extend it still farther. No one, after what he has experienced in all sorts of bodies that he has been used to, can reasonably doubt, whether other bodies, of different sorts, are not possessed of gravity as well as these; and from what he has observed in all bodies, where he can make experiments, he may conclude, that this property of gravity belongs to all bodies universally, and that the moon gravitates towards the earth. It is thus that we are enabled, by a sufficient number of particular experiments, to draw general conclusions.

If you look back into the state of philosophy in the different ages, you will learn from the history of every period, that as far as philosophers consulted nature, and proceeded on observation, they advanced in true knowledge; but as far as they endeavoured to build schemes on any other foundation, they only multiplied disputes and errors.

Wisely, therefore, does Lord Bacon consider

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* Maclaurin's Sir Isaac Newton's Discoveries, p. 22.

natural philosophy as a vast pyramid, that ought to have the history of nature for it's basis, an account of the powers and principles that operate in nature for it's second stage, and the formal and final cause of things for it's third stage. But as for the summit of this pyramid, the supreme of nature, *opus quod operatur Deus a principio usque finem*, he doubts whether it will ever be attainable by man.

I cannot offer to your attention, as a conclusion to this Lecture, any thing more pertinent to the researches you are engaged in, than the devout aspirations of a disciple of the *Stagyrite*, * only so far altered as to render them more conformable to the plan of this work.

Assist us, O Lord, our heavenly Father, with the light of that *reason* by which thou lightenest the world; by which grace and beauty is diffused through every part, and the welfare of the whole is uniformly upheld. So teach us to know ourselves, that we may attain that knowledge, which is worth attaining.

Teach us to be fit actors in that drama, where thou hast allotted every being, great and small, it's proper part, the due performance of which is the one chief end of it's existence.

Enable us to curb *desire*, and keep it always within the bounds of rectitude. Be our first work to escape from *wrong opinion* and *bad habit*; that the mind being rendered sincere, and the heart incorrupt, we may with safety proceed to seek our genuine good and happiness.

When we are thus previously exercised, thus duly prepared, let not our *love* there stop where

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* Mr. Harris.

it first begins; but insensibly conduct it, by thy invisible influence, till it is conjoined to thee, in whom only it can find what is adequate and full. Teach us to love *thee*, and thy divine *administration*; to regard the universe as our true and genuine country; and let the streams of our beneficence be extended to the whole of mankind. Be it our endeavour by an humble spirit, a gentle deportment, and an unfeigned good nature, to soften every care, alleviate every pain, and thus render all around us happy.

Let our life be a continued scene of *acquiescence* and of *gratitude*, of gratitude for what we *enjoy*, and of acquiescence in what we *suffer*; and enable us to co-operate with cheerfulness in whatsoever thou ordainest; that so we may know no other will than thine alone, and that the harmony of our *particular* minds with thy *universal* may be steady and uninterrupted through the period of our existence.

Turn our minds from all that is abject, servile, and evil, and enable us to embrace and cherish only what is generous, lovely, fair, and Godlike.

Let it be our study and delight to behold in the silent mirror of contemplation, those forms which are hidden to human eyes; that animating *wisdom*, which pervades and rules the whole; that *order*, irresistible, immutable, supreme, which leads the willing, and compels the averse, to co-operate in their station to the general welfare; that magic divine, which, by an efficacy past comprehension, can transform every appearance, even the most hideous, into beauty, and exhibit all things fair and good to *thee*, *who art of purer eyes than ever to behold iniquity*; the sole
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and only Lord and Saviour, a never-ceasing, ever overflowing ocean of meekness, delight, goodness, patience, and mercy, ever giving forth the same gifts of goodness and truth, of light and love, blessing and joy, to angels and men.

LECTURE XV.

ON OPTICS.

THE advances made in the knowledge of optics in the last and present age, are such as do honour to human nature and philosophy. *The theory of light and colours* by Sir Isaac Newton, is a piece so excellent for invention, for judgment in conducting experiments, and for drawing the proper conclusions from them, that had it been *Newton's* single work, it would not only have done honour to him, but to the country that gave him birth.* Of the faculties called the five senses, sight is without doubt the most noble; the rays which minister to this sense, and of which without it we could never have had the least conception, are the most wonderful and astonishing part of the inanimate creation.

Of this you will be satisfied when you consider their extreme minuteness; their inconceivable velocity; the regular variety of colours which they exhibit; the invariable laws according to which they are acted upon by other bodies, in their reflexions and refractions, without the least change of their original properties; and the facility with which they pervade bodies of great density, and of the closest texture, without resistance, without disturbing one another, without giving the least sensible impulse to the lightest bodies.

Heat and light may be considered as the children of fire, as kindred qualities produced by the same cause, sometimes exerting their powers separately, sometimes united. We are, however, very ignorant of the intimate combinations of light,
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* Sir J. Pringle's Discourses, p. 233.

and it's mode of acting upon different bodies. Experiments upon vegetables give us reason to believe, that light combines with certain parts thereof, and that the green of their leaves, and the various colours of their flowers, are chiefly owing to this combination: for plants, which grow in darkness, are perfectly white, languid, and unhealthy: to make them recover vigour, and acquire their natural colours, the direct influence of light is necessary. Somewhat similar takes place even upon animals, and mankind degenerate to a certain degree, when confined too closely, or employed in sedentary manufactures. Though the sun is many millions of leagues from you, yet you *see* it as *evidently*, and *feel* it's influence as *powerfully*, as if it were within your reach: it is *within your existence*. It supplies comfort and life to your animal body and life; and you could not survive an hour without it's influence and operations.

Light is diffused on every side from it's fountain the sun: joined with air, it gives beauty and fruitfulness to the earth, supports vegetable and animal life, and the various kinds of motions throughout the system of nature. By their manifold and beneficial operations, as well as by the beauty and magnificence they produce, they point us to HIM who in scripture is called the GLORY OF GOD, by whom all things were made and are upholden. And the *firmament*, the expansion of the celestial elements, *sheweth his handy work*, not only as *Creator*, but as *Redeemer* of the world. The labours of our instructors in the natural world know of no intermission, but incessantly lecture us in the science of divine wisdom. The sun shines forth by day, the moon and stars by night; though they are not endowed like man with the faculty of speech, yet they address themselves to the mind of the intelligent beholder

holder in another way, by the way of picture and representation.

Light introduces all nature to us, the trees, the flowers, the crystal streams, and azure sky: the fixed parts of nature are eternally entombed beneath the light; and we see nothing in fact but a creation of colours; nothing is an object of vision but light; that which we call body or substance, that which reflects the various colours of light, lies hid beneath the appearance, is wrapt in impenetrable obscurity. *Matter*, at first sight, seems to be the only being we have correspondence with, to meet us every where; but when we examine, it shrinks like a phantom behind perception; we know it not; the closer we investigate it's nature, the more it glides away from us, and all that we can at length ascertain, only points it out as a shadowy shroud, under which SOVEREIGN POWER retires from plain view, and acts by regular laws.

The eye is the instrument by which we perceive the effects of light; it's structure, it's appurtenances, the various contrivances for performing all it's internal and external motions, clearly point it out to be the work of Divine Wisdom; and he must be very ignorant of what has been discovered concerning it, or of a very strange cast of understanding, who can seriously doubt, whether or not the rays of light, and the eye, were made for one another with consummate wisdom and perfect skill in optics.

If you were to suppose an order of beings endued with every human faculty but that of sight, how incredible would it appear to such beings accustomed only to the slow information of touch, that by the addition of an organ consisting of a ball and socket of an inch diameter, they might be enabled in an instant of time without changing their place to view the disposition of a whole army, or

the order of a battle, the figure of a magnificent palace, or all the variety of a landscape? If a man were by feeling to find out the figure of the peak of Teneriffe, or even of St. Peter's church at Rome, it would be the work of a life-time.

It would appear still more incredible to such beings as we have supposed, if they were informed of the discoveries that may be made by this little organ in things far beyond the reach of any other sense; that by means of it we can find out our way upon the pathless ocean; that we can traverse the globe, determine it's figure, it's dimensions, and delineate every region; that we can measure the planetary orbs, and count the number of the heavenly host.

Would it not appear still more astonishing to such beings, if they should be farther informed, that by means of this same organ we can perceive the tempers and dispositions, the affections and passions of our fellow-creatures, even when they want most to conceal them? That by this organ we can often perceive what is strait and crooked in the mind as well as the body; that it participates of every mental emotion, the softest and most tender, as well as the most violent and tumultuous; that it exhibits these emotions with force, and infuses into the soul of the spectator the fire and the agitation of that mind in which they originate? To many mysterious things must a blind man give credit. If he will believe the relations of those that see, his faith must exceed that which the poor sceptic derides as impossible, or condemns as absurd.* It is not, therefore, without reason, that the faculty of seeing is looked upon as more noble than the other senses, as having something in it superior to sensation, as the sense

* Reid's Inquiry into the Human Mind, p. 152, 155.

sense of the understanding, the language of intelligence.

The evidence of reason is called *seeing*, not feeling, smelling, tasting; nay, we express the *divine knowledge* by *seeing*, as that kind of knowledge which is most perfect in ourselves.

Truth is of the nature and essence of God, incapable of a verbal definition, but may be illustrated by the similitude of *light*. Between the objects of the mind and corporeal things, the objects of outward sense, there may be found in many respects a very natural and just analogy, as it is, indeed, natural to expect; every *corporeal* form being but the image or resemblance of some *mental* form. Hence you find in sacred writ, *light* applied as a name to the Supreme Being; for as the *sun* is the *fountain* of *external light* to this visible world, so is the *Divine Mind* the fountain of intelligence or intellectual light. Thus also the different kinds of good which run throughout the whole external universe, may be considered as beams emitted forth from the *goodness* of the *Divine Being*; and though the *intellectual sun*, who enlightens the whole *intelligent* or spiritual world, be uniform in his essence, like uncoloured light; yet as he beams around on all things, without exception or intermission, his rays take a diversity of tints from the diversity of objects on which they fall, or the different lights in which the same object is considered: or, as a *ray* of the *sun*, that *sublime* and *significant* emblem of TRUTH, passing through a prism, is divided into a beautiful variety of shades and colours, so that ray of truth, which is shed down from heaven on the human mind, as it passes through different mediums of knowledge, differs in strength and degree, and exhibits an illustrious specimen of that beauty and variety in appearance and effect which distinguish all

all the works of God. The influence of our *intellectual sun* never ceases, nor will it ever miss of accomplishing it's divine ends in all such minds as *open* themselves to *receive* the aid of his benign irradiation.

I shall not, perhaps, find a more suitable opportunity of illustrating to you the words of the apostle, (and by this illustration pointing out to you one of the great ends of natural philosophy,) that *the invisible things of God are clearly seen from the creation of the world, being UNDERSTOOD by the things which are made.* The whole natural world, throughout the sacred oracles, is referred to as a figure of the spiritual. You will find this subject placed in a very clear light by the Rev. Dr. Tatham, * in vol. ii. of his "Scale and Chart of Truth," a work to which I have already referred you. In this dark and sublunary state, wedded to sense, immured in body, and involved in matter, we possess no faculties by which we can form any *immediate* conception of God and spiritual beings. † Between the visible and invisible worlds an impassable gulph is fixed, an impenetrable chasm, through which not a ray of celestial light can *directly* dart. All our information, therefore, of things that are divine must be conveyed through an *indirect* channel.

You

* Tatham's Scale and Chart of Truth, vol. ii. p. 121; vol. i. p. 185. See also the works of Lord Bacon, Dr. Horne, Bishop of Norwich, and those of the Rev. William Jones.

† Plato has a most beautiful passage on this head, saying, "That they who contemplate an eclipse of the sun, unless they view the image of the sun in water, or some such thing, lose their own *eye-sight*, by gazing attentively upon an object brighter than it can bear." That is, the mind by contemplating too closely the *τα οὐρα*, and endeavouring by it's own internal energy to behold them as they are in themselves, will be dazzled and stupified; but by having recourse to sensible objects, and reasoning from an analogy in nature, it may contemplate them without being impaired.

You know that by analogy in human language we transfer material impressions to mental subjects, and can thereby communicate and consider these with certainty and precision ; so, by a similar, but higher transfer from things which are human, material, or mental, to those which are divine, human language is converted into an indirect but certain instrument of this celestial communication.

OUR LORD, in condescension to the capacity and apprehension of mankind, hath graciously and abundantly employed this analogy as a medium to render us capable of receiving the mysteries of religion. This divine analogy is founded, like the human, upon a similitude consisting in a *perfect resemblance and correspondent reality* between the terrestrial things and ideas, which are the direct objects of the human intellect, and those celestial truths of which it can have no direct conception; and it is expressed by transferring the words which stand for the terrestrial things, and the ideas to celestial truths, which words are to be taken in their plain and obvious, not figurative sense ; so that the comparison is founded on something *real* as well as similar ; from which real similarity, reason deduces a just and true correspondence.*

Instead of giving men new and spiritual ideas of heavenly things, different from those they have by nature, and instead of using a spiritual language or mode of communication calculated directly to express heavenly truths, (which would be to change their nature at once) this analogy takes men as

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* This is not, says Bishop Butler, an *apparent and metaphorical similitude* ; it is the substituting the *idea or conception* of one thing to stand for and *represent* another, on account of a *true resemblance and correspondent reality* in the *very nature* of the things compared. It is defined by Aristotle an *equality or parity* of reasoning, though the parity of reasoning is rather built on the *similitude and analogy*, and consequent to them, than the same with them.

they are, and only transfers their words and ideas from earthly to heavenly subjects, by which divine and wonderful expedient, the *invisible things of God* are CLEARLY *seen*, being UNDERSTOOD by the things that are made.

By this method of divine revelation, so *necessary*, so *real*, so *clear*, and certain, the Almighty has, as it were, bowed the heavens, and come down, in wonderful condescension to the blindness and imperfection of human reason, speaking to us of himself in our own ideas and words, with the utmost familiarity, *as a man speaketh to his friend*, and enabling us to speak of him as far as we are concerned, with all reverence and adoration, but with as much ease and certainty as of each other.

In the explication of his mysteries (says Lord Bacon, our divine philosopher) God vouchsafed to descend to the weakness of our capacity, so expressing and unfolding them to us as they may be best comprehended by us, inoculating, as it were, his revelations upon the conceptions and notions of our reason; and so applying his inspirations to open our understanding, as the figure of a key is fitted to the wards of a lock. We ought not, however, on this account, to be wanting to ourselves; for seeing God makes use of the faculty and functions of reason in his divine illuminations, we ought every way to improve the same, in order that we may be more capable to receive and entertain such holy mysteries.

OUR LORD, who is himself the fountain and conductor of *truth*, is represented in the sacred oracles as the SUN, the fountain of LIGHT, and as the DAY-SPRING FROM ON HIGH, the harbinger of LIGHT; and of these apt similitudes familiar to all, even without an explanation, he often availed himself, expressing *truth* by the significant emblem of LIGHT, and the LIGHT OF LIFE.

He by whom all things were made hath delegated to the *sun* the power of enlightening the material system, while he hath reserved to HIMSELF the office of giving light and knowledge by his eternal TRUTH to the mind of man. But whether he acts through the *instrumentality* of his creatures, or more *immediately* from himself, he is uniform and consistent in his operations; so that one part of his creation is always illustrative of another.

The sun, in performing his daily splendid office, beams forth light and life throughout our system, and proclaims, in language known to all, *it's Maker's* sacred glory, whose power supplies the never-failing fountain with it's endless beams, and makes it a representative of his invifible glory. Thus as the SUN sheds his light over the material creation to be apprehended by the eye, so TRUTH is the light shed down from heaven to be apprehended by the intellect, given to illumine every subject natural and moral, corporeal and spiritual, as far as they are qualified by their different natures to convey it to the human mind, or rather perhaps so far as the human mind is *qualified* to receive it from them. For the difficulty of receiving truth does not exist so much in the subjects as in ourselves; and truths which are the strongest, may sometimes shine upon our mind with the weakest force.

In order to instruct us, the sacred scripture always places some natural object before the eye of the understanding; and as the *visible* world is throughout a pattern of the *invifible*, the figures of the sacred writers built upon the images of nature, are as extensive as the world itself. The world being thus an image or shadow of heavenly things, *natural philosophy*, when employed in unfolding the works of creation, and applying them to their true end, is a *school* in which God is the

teacher; and all the objects of sense in heaven and earth, and under the earth, are the letters of an universal language, in which you and all mankind have a common interest.

Words are changeable, language has been confounded, and men in different parts of the world are as unintelligible to one another as barbarians: but the visible works of creation are not subject to any such confusion, they speak to us the same language as they spoke to Adam, and their language will last as long as the world shall remain.

Thus, for example, if you take the word God, you have a sound which gives you no idea; and if you trace it through all the languages of the world, you find nothing but arbitrary sounds with great variety of dialect and accent, all of which still leave you where you began, and reach no farther than the ear. But when it is said, *God is a sun and a shield*, then *things* are added to words, and you understand the extent of the power and the influence of the Being, signified by the word God; you conceive *him* to be the author of light to the understanding, the fountain of life to the soul, it's security against all terror, it's defence against all danger. Such is the difference between the language of *words* and the language of *things*. If an image is presented to the mind, when a sound is heard by the ear, then we begin to understand, and a single object of our sight in figurative acceptation will give you a larger and more instructive lesson than ever could be conveyed by all the possible combinations of sounds.

In the preceding Lectures on fire you have seen how every thing subsists, and is preserved in the midst of an element capable of destroying and consuming all things, and yet by it's spontaneous action, it never destroys any thing.

I have

I have now to treat of another agent; LIGHT is a property of fire; by it's operation it makes us pass in the twinkling of an eye from a state of the thickest darkness to that of the brightest day; it gives us as it were a new existence, making us go out of ourselves, and enter into communion and commerce with the most distant objects. Heat and light are undoubtedly the offspring of fire; but we are equally unable to draw the line of separation, or to trace the bond that unites them. You need not be surprized at these various modifications of the same fluid, when you reflect on what you have already seen in this world, where *beauty* is so *diversified*, where *being* is so *multiform*, and yet where one and the same face of things is ever presented to your view.

As the *eye* among the organs of body, so *optics* among the branches of natural philosophy, is the most noble, curious, and useful; and this whether it is treating of simple vision, of that through glasses, or of the effects of mirrors, all still relates to the eye, and you are intimately concerned in all the phenomena of which it treats. If you cast your eyes on a large plain, and run rapidly over all the objects thereon, in an instant their image is exactly painted at the bottom of your eye; if you look through a telescope at a distant object, it appears as if it were within a few inches of the eye. Does age weaken the sight? a convex glass restores it again; if the eye be so formed as not to be capable of viewing distant objects, a concave glass remedies the defect. Have you occasion for heat beyond the strength of the furnace? optics will instruct you how to obtain it from the solar rays. With a prism in your hand you decompose those rays, and shew that the rays of light which appear to us uncoloured, consist of seven primitive colours.

Amongst the various inventions of human art, there are none so justly entitled to your admiration, as those which enlarge the powers of vision. And the discovery of *optical instruments* may be esteemed amongst the most noble, as well as amongst the most useful gifts which the SUPREME ARTIST has conferred on man. For all admirable as the eye came out of the hands of HIM who made it, yet no organ of the animal frame hath HE permitted to be so much assisted by human contrivance, not only for the uses and comforts of life, but for the advancement of natural science, whether as in *microscopes*, by giving form and proportion to the minute parts of bodies (as it were to the atoms of nature) imperceptible before; or, by contracting space, as by the *telescope*, and, as by magic art, bringing to view the grander objects of the universe, the immense distances of which had either disguised their aspect, or rendered them quite invisible.*

Yet so singular are the dispositions of men who term themselves philosophers, that you will find them on the one hand denying the existence of *all spiritual beings* and *spiritual agency*; and on the other, sooner than own and acknowledge the unity of design and wisdom, that is evident in all parts of creation, they will embrace the greatest absurdities, and make fire and light to be mere *qualities*. That light is, however, the action of a material, real substance, will become very evident to you by a few considerations.

1st. The motion of light is progressive, like all other bodies; and it has been proved by astronomers, that it takes about seven or eight minutes in passing from the sun to the earth. This discovery was first made by *Mons. Romer*, who having observed, that the eclipses of the *satellites of Jupiter* appeared

* Sir John Pringle's Discourses.

appeared sooner or later than they ought by theory, according as the earth was nearer to, or farther from, Jupiter, concluded from thence that the motion of light was not instantaneous; and by observing the different times of the appearances of these eclipses, according to the different distances of the earth from Jupiter, discovered the time it took up. This theory was further confirmed by a notable discovery of Dr. *Bradley*, of an apparent motion of the fixed stars, and elegantly accounted for by the motion of light.

From Dr. *Bradley*'s observations it appears, that light is propagated as far as from the sun to the earth in 8 minutes 12 seconds. And it likewise appears, that the velocity of light is uniform and the same, whether original, as from the stars, or reflected, as from the satellites of Jupiter.

2. Light may be stopped, or resisted, in it's passage from one place to another by the interposition of an opaque body, as other fluids are stopped in their courses by the opposition of any solid substance.

3. Like all other bodies in motion, it may be turned out of it's rectilinear course, and have the determination of it's motion changed; it may be collected into a small, or scattered through a large space.

4. It acts upon the organs of animals, and upon all other bodies, in a similar manner to other fluid substances, striking them with a determined force, communicating to them a certain degree of motion, and separating their component parts.

The velocity of light being known, we should be able to estimate the magnitude of it's particles, if we were in possession of good observations of the effect of their momentum. For example, it is found that a ball from a cannon at it's first discharge flies with a velocity of about a mile in 8 seconds, and

would therefore arrive at the sun in 32 years, supposing it to move with unremitted velocity. Now light moves through that space in about 8 minutes, which is two million times faster. But the forces with which bodies move are as their masses multiplied by their velocities: if therefore the particles of light were equal in mass to the two millionth part of a grain of sand, we should be no more able to endure their impulse than that of sand when shot point blank from a cannon.*

DEFINITIONS.

The cause and nature of vision is properly the subject of that part of philosophy which is called by the name of *optics*. But as light is a principal instrument in effecting vision, the word optics is used in a more extensive sense, and every thing in philosophy is looked upon as a part of optics, which relates to the nature and qualities of light.

When the word OPTICS is used in the stricter sense for the theory of vision, the science of optics is divided into two parts; one part is called *dioptrics*, and the other *catoptrics*.

The laws of *refraction*, and the effects which the refraction of light has in vision, are the subject of *dioptrics*.

The laws of *reflexion*, and the effects which the reflexion of light has in vision, are the subject of *catoptrics*.

These distinctions will however be of little use to us, nor will it be worth our while in these Lectures to keep the branches of optics distinct from each other.

Whatever is seen, or beheld by the eye, is by opticians called an *object*.

They

* Nicholson's Introduction to Philosophy, vol. i. p. 256.

They consider every *luminous object* as made up of a vast number of minute points; and that each of these points, by an unknown power, sends forth rays of light *in all directions*; and is thus the center of a sphere of light extending indefinitely on all sides. To render this clearer, consider this small brilliant object that I place upon the table, and you will find, that you can see it from any part of the room; it is therefore evident, that rays of light must proceed from all parts of it, and extend indefinitely on all sides.

By a *ray* of light, is usually meant, the least particle of light that can either be intercepted alone, whilst all the rest are suffered to pass, or that can be let pass alone, whilst all the rest are intercepted.

Any parcel of rays diverging from a point, considered as separate from the rest, is called a *pencil of rays*.

By a *medium*, in the language of opticians, is meant any pellucid or transparent body, which suffers light to pass through it. Thus water, air, a diamond, and glass, are called mediums.

One medium is said to be more *dense* than another, when it contains more matter in the same bulk and size: thus glass is more dense than water, water is more dense than air.

A small object, or physical point of an object, considered as propagating light towards a certain part, is sometimes called a *radiant*, or *radiating point*.

Those rays which proceed from any point at a very great distance, may be considered as *parallel* rays; for the greater the distance of the point from whence rays flow, the nearer do they approach a parallel direction.

Of

OF THE GENERAL PRINCIPLES ON WHICH OPTICAL DEMONSTRATIONS ARE FOUNDED.

To illustrate and explain some of the general principles of optics, I shall darken this room, and only admit the light by a small hole: opposite to the hole I shall place a white screen. Now if you look at the screen, you will observe thereon a picture of all the exterior objects which are opposite to the hole, with all their natural colours: the colours are faintly depicted; the images of the objects that are stationary, as houses, trees, &c. are fixed and stationary in the picture; while the images of those that are in motion, as those of horses, &c. are seen to move. You observe that the image of every object is *inverted*; this is occasioned by the rays of light crossing each other as they pass through the hole. The sun shines this moment on the hole, as you may see by the luminous ray proceeding from it to the screen. Now if either of you will place your eye in this ray, you will find that your eye, the sun, and the hole, are in one and the same strait line. It is the same with every other object which is depicted on the screen. The images of the objects are smaller in proportion as the objects are further from the hole.

Let us now consider a few among the many important inferences that may be deduced from the foregoing experiment.

It must be evident to you, that *light moves or acts in a strait line*; for you saw that your eye, the image of the object, and the object, were always in a right line. This is also plain from the shadows which opaque bodies cast; for if the light did not describe strait lines, there would be no shadow: it is equally plain from lights finding no passage through bent tubes.

As

As the rays of light are constantly propagated in right lines from luminous bodies, whenever I have occasion to represent a ray of light, I shall do it by a strait line reaching from a luminous body to the body illumined; that is, I shall speak of the line which the ray describes, as if it was the ray itself.

It is manifest also that light consists of parts both successive and cotemporary, because in the same place you may stop that which comes one moment, and let pass that which comes presently after; and at the same time you may stop it in any one place, and let it pass in any other. In other words, the light which falls upon an object all at once, at the same instant, is *cotemporary*; the light which from time to time continues to fall on an object is *successive*, consisting of parts following one another.

A second inference deducible from our experiment is, *that a luminous point may be seen from all places to which a strait line can be drawn, without meeting with an intervening obstacle.* This must be evident to you, when you remember that the picture of an object in motion in these experiments was visible as long as it was in a line with the hole and screen.

It follows from hence, that *a luminous point, by some unknown power, sends forth rays in all directions, and may be considered as the center of a sphere of light extending indefinitely on all sides.*

This you may understand still better by looking at *fig. 1, pl. 1*; where you find the point O of the dart is visible to an eye placed in either of the situations A, B, C, D, E, F, G.

If you conceive some of these rays to be intercepted by a plane, then is the luminous point the summit of a pyramid, the body of which is formed

formed by the rays proceeding therefrom; the base is the intercepting plane.

The image of the surface of an object on the screen, is also the base of a pyramid of light, the summit of which is the hole. The rays which form this pyramid cross at the hole, and there form another pyramid, of which the hole is again the summit, but the surface of the object is the base.

An object is visible, because all its points are radiant points. Rays of light are incessantly propagated from every physical point of an object, otherwise the whole object would not be visible; and that all at once, and to all positions of the eye.

For wheresoever a spectator is placed with respect to a luminous body, every point of that part of the surface which is turned towards him, is visible: each point is therefore a radiant point, emitting rays in all directions; and those rays only are stopped in their passage by an interposed object, which would be intercepted upon the supposition that the rays move in right lines.

Another inference which you will make, is this, *that the particles of light are indefinitely small*; for the rays which proceed from the points of all the objects opposite to the hole, pass through it, without confounding or embarrassing each other. Exquisitely minute they must be, when myriads can move all manner of ways without impinging one another; and that this is the case, you cannot doubt, since different bodies, and different parts of the same body, are distinctly visible at the same time. How curious must be the texture of the eye to be sensible of these small impulses, and to distinguish at the same time those from different objects!

If you make a hole with a pin in a piece of paper, and look through it, you see all the objects that are before you, be they ever so many; now since these objects, and each point of these objects

become visible by means of the rays of light coming from thence to the object, you may form some idea of their extreme minuteness. If a common tallow candle be lighted, and set by night on a high tower, it may be seen all round at the distance of half a mile from the tower: wherefore there is no place within a sphere of a mile diameter in which the eye can be placed, where it will not receive some rays from this small flame. Rays of light will pass without confusion through a small puncture in a piece of paper, from several candles in a line parallel to the paper, and form distinct images on a sheet of pasteboard placed behind the paper.

*Every ray of light carries with it the image of the point from which it was emitted.**

If therefore all the rays coming from any point are united in the same order in which they proceeded, or were emitted, there will be a perfect representation or image of that object, at the place where they are thus orderly united.

Another property in the rays of light is their REFLEXIBILITY, or disposition of being turned back into the medium from whence they came; and in this they observe the same mechanical laws with other bodies in their reflexions, that is, *the angle of reflexion is always equal to the angle of incidence.* The truth of this position may be confirmed by many experiments; one or two will be sufficient. Let us return to our dark room, and I shall, by means of a mirror without, let a beam of solar light pass through the hole upon this part of the floor; where the beam falls I put a looking glass; I now fill the room with dust to render the beam of light more visible, and you see that it is reflected back into the air; and that the inclination of the reflected

* De la Caille, Leçons d'Optique, p. 24.

lected beam is exactly the same as that of the incident beam. This law may be confirmed by another easy experiment, which I will shew you in the next room. Here is a graduated semicircle, at the center of which is a small piece of looking-glass. I place a small object on the graduated edge of the semicircle, and on the opposite quadrant thereof, and exactly at the same angle, I place the sight. Now if either of you look through the sight, you will see the object; but if you remove the sight-piece a little higher or lower, you will not perceive the object.

OF REFRACTION.

There is another property of light, which is it's *refrangibility*, or disposition to be *refracted*, or turned out of it's strait course, in passing *obliquely* out of one medium into another of different density.

This *refraction* is greater or less, that is, the rays are more or less bent and turned aside from their path, as the medium through which they pass is more or less dense. Thus, for instance, the rays are more refracted in passing from air into glass, than from air into water; and glass is you know much more dense than water; the denser the medium, the more the rays are bent, and approach a perpendicular let fall upon it's surface. I would be understood always to speak of the rays which fall obliquely upon these mediums; for those rays which fall perpendicularly do not suffer any deviation, the *refraction only taking place when the rays fall obliquely*, and is so much greater as their incidence is more oblique, and the medium more dense. After having taken the new direction, the ray again proceeds invariably in a strait line, till it meets with a different medium, when it is again turned out of it's course.

Take

Take an empty bason, and at the diameter of the bottom fix marks at a small distance from each other; then take it into the dark room, and let in a ray of light; and where this falls upon the floor, place your bason, so that it's marked diameter may point towards the window, and so that the beam may fall on the mark most distant from the window. This done, fill the bason with water, and you will observe that the beam which before fell upon the most distant mark, will now by the refractive power of the water be turned out of it's strait course, and will fall two or three, or more marks nearer the center of the bason.

Make the water in the bason muddy, but not so much so as to destroy it's transparency, which you may easily do, by dropping therein a few drops of milk, or dissolving in it some grains of saccharum saturni; then fill the room with dust, and the beam of light will be very visible, both in it's passage through the air and the water, and you will observe very distinctly three beams, that of *incidence*, which in coming through the hole, falls obliquely on the water; that of *reflexion* from the surface of the water, making the angle of reflexion equal to that of incidence; and that of *refraction*, which from the surface where it was bent, moves on in a strait line to the bottom of the bason. All things remaining the same, place a small piece of looking-glass at the bottom of the bason, where the *refracted* beam falls, and it will thereby be reflected back again through the water, and in passing out of the water into the air will be again refracted or turned out of it's course.

Another, though very common experiment, will give you a clear idea of the power of refraction; place a piece of money at the bottom of this bason, and walk back therefrom till you cannot see the piece of money; let some water be poured into the
bason,

basin ; and as before you could not see the piece of money *where it was*, you will now see it *where it is not*. It is not your eye that has changed place, but the ray of light has taken a new direction in passing from the water into the eye, and strikes your eye as if it came from the piece of money. This experiment seldom fails to surprise those, who are unacquainted with the properties of light ; as they do not comprehend how the filling the vessel with water can make them see an object placed at the bottom, and which was not visible to them before, being concealed by the edge of the vessel.

The advantages we derive from the refraction of light are inestimable : without this property we should have figured glasses in vain, and telescopes and microscopes would not have existed. The refraction of light at the surfaces of transparent bodies was taken notice of by the ancients. *Aristotle* has a problem concerning the apparent curvity of an oar in water. And *Archimedes* is said to have written on the appearance of a ring or circle under water. *Albazen* the Arabian, and *Vitellio*, thought that the angles of incidence and refraction were in a given ratio ; but the proportion they laid down being found erroneous in large angles, the subject was examined more strictly by the moderns. Kepler among the rest made several experiments concerning it, and though he missed his aim, his attempts and conjectures were useful to others. After the invention of the telescope, this subject being thought more valuable than before, was farther pursued ; and *Snellius* found out the truth : but *Descartes* was the first who published, that the *sines of incidence and refraction* (and not their angles) *are in a given ratio*.

In explaining this subject, as well as in other parts of optics, I must have recourse to diagrams,

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as the theory will require all your attention; but you will not, I hope, permit the thorns and briars which interrupt the path of science, to prevent your proceeding therein; for whatever is *good* can only be obtained by *labour*; and science, like virtue, disdains the *slothful* and the *negligent*.

Let B C, *pl. 1, fig. 2*, represent the surface of water, or any other transparent medium denser than air. Let A be the point of incidence, in which any ray coming through the air from F, falls upon the surface of the water, where it is refracted from it's strait course A K in the line A G. About A as a center with the radius A F describe the circle B F C K E; at the point of incidence A, erect a perpendicular A D, and produce it downward to E; from F upon the line A D, let fall the perpendicular F H, and from G upon A E, let fall the perpendicular G I.

The *angle* F A D, which the incident ray F A makes with the perpendicular D A, is *the angle of incidence*. The line F H is the *sine* of the angle of incidence F A D.

The *angle* G A E, which the refracted ray G A makes with the perpendicular A E, is the *angle of refraction*. The line G I is the *sine* of the angle of refraction.

The angle K A G contained between the line of direction of an incident ray, and the direction of the same ray after it is refracted, is *the angle of deviation*.

These things being understood, I may now mention to you the laws of refraction, which have by repeated experiments been found to be general and without any exception.

1. *The angles of refraction and incidence lie in one and the same plane*, that is, in the plane drawn through the incident ray, and the perpendicular at the point of incidence.

2. *The rays of light are always refracted when they pass OBLIQUELY from one medium into another, whose density is different from that of the first.*

3. *A ray of light falling obliquely upon the surface of a denser medium is refracted towards the perpendicular, that is, so that the angle of refraction be less than the angle of incidence: on the contrary, the refraction out of a denser medium into a rarer, as out of glass into air or water, is made from the perpendicular, so that the angle of refraction be greater than the angle of incidence.*

4. *When a ray of light is refracted out of air into a given medium, or out of a given medium into air, the sine of the angle of incidence is to the sine of the angle of the refraction in a given ratio; in other words, there is a certain and immutable law or rule by which refraction is always performed; and that is this: whatever inclination a ray of light has to the surface of any medium before it enters, the degree of refraction will always be such, that the proportion between the sine of the angle of it's incidence, and that of the angle of it's refraction, will always be the same in that medium.*

Hence if that proportion be known in any one inclination of the incident ray, it is known in all inclinations, and thereby the refraction in all cases of incidence on the same refracting ray may be determined.

When a ray of light is refracted out of air into glass, the sine of incidence is to the sine of refraction as 31 is to 20, or as 3 to 2 nearly; or out of air into water, as 4 to 3. Hence the sine of incidence is to the sine of refraction, when a ray passes out of water into glass, as $\frac{3}{4}$ to $\frac{20}{31}$, or as 93 to 80.

5. *A ray of light cannot pass out of a denser medium into a rarer, if the angle of incidence exceeds a certain*

a certain limit; * that is, when the sine of incidence has a greater proportion to radius, than it has to the sine of refraction.

A ray of light will not pass out of glass into air, if the angle of incidence exceeds $40^{\circ} 11'$, the sine of which is $\frac{20}{31}$ parts of the radius; or out of glass into water, if the angle of incidence exceeds about $59^{\circ} 20'$. Refraction will be changed into reflection.

In general, the densest mediums resist the action of light less than those that are more rare, the angle of refraction being smaller than that of incidence: and on the other hand, the rarest mediums seem to resist it less: and it has been laid down as a law, that all bodies have their refractive powers proportional to their densities, excepting so far as they partake more or less of sulphureous oily particles. Mr. Brissot has shewn, in the memoirs of the academy of sciences for 1777, that the refractive power of inflammable bodies compared together does not follow the ratio of their densities.

6. *All refraction is reciprocal.* If a ray of light is refracted in passing out of one medium into another; then, if that ray was to return back again, it would be refracted just as much the contrary way: or if the refracted ray become the incident ray, then the incident ray will become the refracted one.

When the angle of incidence is increased, the corresponding angle of refraction will also be increased. If two angles of incidence be equal to each other, the angles of refraction will be also equal. In the same manner, if the one be diminished, the other also will be diminished; so that if

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one

* These laws, &c. are demonstrated upon the principle, that light is an homogeneous substance; and though light will appear to be compounded of several rays, yet the principles of refraction, &c. are true when applied to rays of any one sort.

one of these angles becomes infinitely small, the other becomes so also.

The direction of a ray is not changed, if it moves through a medium terminated by two surfaces parallel to each other; for as much as it is turned towards any side at it's entrance, so much is it exactly turned the other way as it goes out of the said medium.

While a ray moves in the same uniform medium, it does not change it's direction.

OF THE FORCE AND INTENSITY OF LIGHT.

In a free medium the force and intensity of light propagated in parallel rays is always the same.

For in such a medium there is nothing to impede it's progress, hinder it's action, retard it's velocity, or change it's direction.

In a free medium the force and intensity of the light, which is propagated by rays proceeding from the same point, are in an inverse ratio of the squares of the distances from this point. This is manifest from the principles of geometry, and I shall soon render it evident to you by experiment.

It scarce, however, wants any experimental proof; for light radiating from a center, it's intensity must decrease, as all rays do that proceed from a center; i. e. must necessarily become thinner and thinner, continually spreading themselves, as they pass along, into a larger space, and that in proportion to the squares of their distances from the body; that is, at the distance of two spaces, they are four times thinner, or less intense, than they are at one, and so on, because they spread themselves in a two-fold manner, upwards and downwards, and sideways.

If the light which flows from a point, passes through a square hole, as *b c d e*, *fig. 3, pl. 1*, be received upon a plane *B C D E* placed parallel to the plane of the hole; and the distance *A B* be double of *A b*; then the length and breadth of the shadow

BD will each be double the length and breadth of the plane bd, and treble when AB is treble of Ab, and so on; as you may easily prove by the light of a candle placed at A.

Hence luminous bodies, or those that shine with their own light, are vastly brighter than opake bodies illuminated by them; for opake bodies disperse the light falling upon them in all manner of ways: whence supposing all the light to be reflected, the quantity received by the eye from the opake body, compared with that received from the luminous body, is only as the visible illuminated surface of the opake body to the surface of an hemisphere, whose radius is the distance of the opake body from the eye; supposing the breadth of the pupil to be the same in both cases, and that the sum of the distances of the opake body from the eye, and from the luminous body, differs insensibly from the direct distance of the luminous body from the eye.

Hence the light of the full moon at a medium is about 300,000 times fainter, or rarer, than the sun's light, when at the same height above the horizon, all other circumstances being the same, as will appear by comparing the moon's apparent disk to the surface of a hemisphere. Whence it is easy to conceive, that since we can bear the sun's heat, we cannot be sensible of any from the moon.

“ Though accurate methods may be used for investigating the intensity of the moon's light, they are too abstruse for our Lectures. But the following consideration is level to every capacity: when the *moon* is visible in the day-time, it's light is so nearly equal to that of the lighter thin clouds, that it is with difficulty distinguished amongst them. It's light continues the same during the night; but the absence of the sun permitting the aperture of

the pupil of the eye to dilate itself, it becomes more conspicuous."

"It follows therefore, that if every part of the sky were equally luminous with the moon's disk, the light would be the same as if in the day-time it were covered with the above-mentioned thin cloud. This day-light is consequently in proportion to that of the moon, as the whole surface of the visible hemisphere is to the surface of the moon, that is, nearly as 90,000 to 1."*

We do not know any medium that is *free*, or *perfectly transparent*; even the air, the most rare and transparent we are acquainted with, is full of opaque particles that impede the light; this is manifest from the phenomenon of a beam of light let in through a small hole in a room, which beam is visible like a *luminous cone* from every part of the room. This shews, that the whole light does not go forward in it's rectilinear course, but that at every point of the medium through which it passeth, some part of it is reflected every way; for the visibility of the luminous cone is caused by this reflection. *The greater faintness of the sun and the moon*, when near the horizon, than when elevated higher up, shews also that their light is more obstructed, the tract of air and vapours being longer in one case than the other. The loss of light in passing through glass is still greater.

The surface also of bodies both transparent and opaque, being for the most part uneven, it necessarily follows, that abundance of light is dissipated even by bodies the most transparent, some being reflected, some refracted towards different parts by their uneven surfaces, whilst other parts are retracted and reflected with some uniformity. This accounts for a person seeing *through* water, and

* Nicholson's Introduction to Natural Philosophy, vol. i. p. 166.

and his image being reflected by it at the same time; and shews why, in the dusk, the furniture in a room may be seen by the reflection of a window glass, whilst objects that are without are seen through it.

The quantity of light contained in any pencil is continually diminished, the greater the distance from the radiant; and this diminution is greater or less, according to the greater or less degree of opacity in the medium through which it passes.

This makes it impossible to assign exactly the different proportions of the density of light, at different distances from the radiant; but in all cases, the decrease of the density of light is greater than the squares of the said distances. And this is the reason why objects appear less bright, the farther they are from the spectator.

If none of the rays were stopt in their passage, the degree of brightness of the picture of an object upon the retina, would be the same at all distances between the eye and the object, supposing the aperture of the pupil of the eye to remain the same. For in that case the magnitude of the picture upon the retina, and the density of light, would increase or decrease together in the same proportion, viz. reciprocally as the square of the distances of the eye from the object; and therefore the density of the light upon the retina would be invariable at all distances. For *example*; when the eye approaches as near again to the object, the picture upon the retina becomes quadruple; and the quantity of light received from the object through the same aperture of the pupil at half the distance is also quadruple; and this being equally spread over four times the surface of the retina, the light is just as dense as before, when the object was at twice the distance.

Luminous bodies shining in the dark, as a lamp or torch, &c. emit to very great distances much more light than in that case is necessary for

vision: and though their light suffers a continual diminution by the heterogeneity of the medium, the farther it goes; yet there being still more left than is necessary for vision, their splendor is not sensibly increased or diminished, by lessening or increasing their distances.

Light is not only diverted out of it's course by reflection from the bodies it meets with, but a great part of it is also frequently suffocated, or as it were destroyed by them; for it is manifest, that black or dark bodies reflect much less light than others of lighter colours; and it is probable that no bodies reflect all they receive.

The power of the eye to discern objects without inconvenience by different quantities of light is very extensive; for not only objects of different colours placed in the same light are seen with equal ease, but even objects so small as the letters of a book may be distinguished and read by a clear moon-light. Now admitting the surface of the eye's pupil to be ten times greater in a weak than in a strong light, yet the proportion of the weakest light to the strongest, by which the eye can conveniently see objects, perhaps does not exceed that of 1 to 10,000. How exquisite are our faculties!

Experience shews, that objects appear so much more obscure as they are more distant, and at last cease to be visible: this obscurity arises from the passage of the rays of light through the air, a medium dense and foul enough to obstruct them in a very great degree, and dissipate a prodigious quantity in the interval between the eye and the object. The experiments and calculation of M. Bouguer shew, that 100th part of the light is lost at 189 fathoms of horizontal distance; that 7469 fathoms, or about $3\frac{1}{4}$ leagues, dissipates one third of the light; and that they cease at last to be visible, because the images by their diminution in size and light

are

are incapable of making a sufficient impression on the eye.

By a calculation founded on experiment, M. Bouguer has shewn, that of 10,000 rays, that proceeding from a star would reach our eye, if it were not for their passing through the atmosphere, there reach it no more than are set down in the following table:

Degrees of apparent Altitude.	Number of Rays.	Degrees of apparent Altitude.	Number of Rays.	Degrees of apparent Altitude.	Number of Rays.
0	5	8	2423	30	6613
1	47	9	2797	35	6963
2	192	10	3149	40	7237
3	454	11	3472	50	7624
4	802	12	3773	60	7866
5	1201	15	4551	70	8016
6	1616	20	5474	80	8098
7	2031	25	6136	90	8123

Mr. Bouguer has also shewn by experiment,
1. That the light of the sun is about 300,000 times stronger than the light of the full moon, when at it's mean distance from the earth.

2. That the light of the sun is not sensible when it is diminished 1000,000,000,000 times, and of course that a body is truly opake when it permits only 1000,000,000,000 part of the sun's light to pass through it.

OF IMAGES AND FOCI.

On account of the extreme minuteness of the atoms of light it is clear, that a single ray, or even a small number of rays, cannot make a sensible impression on the organ of sight, of which the fibres are very coarse when compared to the rays of light.

A great

A great number of rays of light proceeding from the same point or portion of the surface of the body are necessary to render this portion visible. But as the rays of light proceeding from the same point are wider from each other the farther they extend, it has been necessary for particular purposes either to bring them near and unite them together in a point, or to separate them from each other.

We are able by the assistance of glasses to unite, in one sensible point, a great number of rays proceeding from the same point of an object; the rays thus united in a point form an image of that point of the object from which they proceed; this image is *brighter* in proportion as there are more rays united, and more *distinct* in proportion as the order in which they proceed, is better preserved in their union. On placing a polished and white plane at the place of their union, you will see this image painted in all its proper colours, if no adventitious light is permitted to disturb or render it confused.

The point of union of the rays of light formed by means of a glass lens, or a mirror, is called the *focus* of this glass or mirror. If this union is real, the focus is called a *real focus*, or simply *focus*: it is the place where the image of the object is formed, and proceeds to form another image in the eye, as if it were the real object. If this point of union is nothing more than a point, to which the rays in the new direction which has been given to them tend, but are not actually united, this point is called an *imaginary focus*. It is also the place where the *object appears really to be*, when several of the rays which have been dispersed, enter in sufficient quantity into the eye to form a sensible image of the object. For an object always appears to be in that place from whence its light seems to come to our eye.

Since every ray carries with it the image of
the

the object from whence it proceeds, it follows, *that if the rays, after having crossed each other, and having formed an image at their intersection, are again united after either reflection or refraction, they will form a new image; and so on for ever, as long as their order is not confounded.* We may thus form images of the same object, as often as we can unite the proceeding rays without confounding them.

It follows, that so long as the progress only of the rays of light are attended to, the image may be considered as the object, and the object as the image; and even a second image, as if the first had been the original object, &c.

The rays of light may be differently disposed relatively to each other, and may be considered as *parallel, diverging, or converging.*

The rays are *parallel* when they always keep at the same distance from each other.

Those rays which, in proceeding from a point, continually recede from each other, are called *diverging rays.*

Those rays are named *converging*, which, proceeding from various parts, approach nearer to each other in their progress, having a tendency to unite in one point.

When two mediums touch each other, their surfaces must be either *plane, or convex, or concave*; and the rays which acting together pass through these mediums, may be considered either as *parallel, converging, or diverging.* We will examine together the effects arising from these different circumstances. In speaking of convex or concave surfaces, I shall only consider those that are spherically such.

OF REFRACTION AT A PLANE SURFACE.

Case 1. *When incident parallel rays pass obliquely from a rare into a dense medium terminated by a plane surface.*

To

To perform the experiments for this and many other parts of optics, I use that part of the solar microscope that carries the mirror, fixing it, as in the present instance, to a window shutter; on darkening the room, I can throw the solar rays into the room, and pass them through the tube belonging to the microscope; I can render them parallel, convergent, or divergent, according to the lens I adapt thereto.

The lens now in the tube makes the pencil proceeding therefrom cylindrical; this pencil, by turning the mirror, falls obliquely on the sides of this box, (*fig. 5, pl. 1.*) whose sides are of glass; each end has a circular aperture for occasionally receiving a watch glass, which may be placed either with the convex or concave side outwards; the box is made water-tight, and is furnished with a cock for more easily emptying it of water.

The ray of light (at A, *fig. 6, pl. 1.*) entering the box filled with water, is refracted to B, and forms there upon this card, placed against the side of the box, a luminous circle, exactly the same size as that which entered the box (at A): on removing the card, and letting the ray of light proceed in the air, you see that it goes on in a direction exactly parallel to the incident ray, being of the same size through it's whole length.

The two pencils of light EA, EA, after being by refraction bent nearer the perpendiculars pp, pp, move on parallel to each other; and on being again refracted, and separating from the perpendiculars sp, sp, you will find by measuring the distance between them that they still retain their parallelism.

From hence it follows, that incident parallel rays passing obliquely from air into a mass of water terminated by a plane surface, preserve their parallelism in entering and going out of the water. The same is true of other mediums which differ in density,

sity, but have only a moderate thickness, as in our present experiment.

This may be further illustrated by a diagram, *fig. 4, pl. 1.* Let $A B C D$ be a solid piece of glass with two parallel surfaces $A B, C D$, and let the incident ray $E F$ be refracted into $F G$; then will $F G$ be refracted by the second surface into $G H$ parallel to $E F$, or in the same direction as $E F$, because the angle at F is equal to the angle of incidence at G ; and therefore the angle of incidence at F will be equal to the angle of refraction at G .

Case 2. *When converging incident rays pass from a rare into a dense medium, and from this again into the same rare medium.*

For this experiment, I put into the tube a lens, somewhat more convex than that we used before; so that the pencil of light that issues from the tube is now in the form of a long cone, whose base is the lens.

I fill the box with water, and present it towards the light, so that the side $A B$, *fig. 7, plate 1*, may be perpendicular to the axis of the cone, and in such manner that the point or extremity of the cone may reach the further side $B C$ of the box.

I empty the box of its water, and the cone of light becomes sensibly shorter, terminating as at E . By bringing the box nearer the window, so that the point of the cone may pass beyond the further side, the cone is no longer of a regular shape, but as it appears at $F G$, and the point is removed somewhat further distant.

This experiment shews, that the rays of light do not converge so soon when they pass from a rare medium into one more dense; and that, on the contrary, they converge sooner than they would otherwise do, when they pass from a dense into a rare medium. In other words, when converging rays go from a rare into a dense medium, they become

come less convergent ; but their convergence is increased in passing from a dense into a rare medium.

Thus, *fig. 18, pl. 1*, the two converging incident rays *ad, bc*, which would meet at *e*, are bent towards the perpendicular by the refracting surface *I H*, and therefore proceed to *E*.

In the same manner the converging rays *lg, fg*, falling upon *I H*, are refracted to *b, b*, instead of going on and meeting at *I* : but on the contrary in proceeding from the refracting surface *K L*, the rays *gb, gh*, are refracted from the perpendicular, and therefore meet sooner as at *K*, than they would otherwise have done : the rays are therefore twice bent, but in contrary directions, once at *h, h*, once at *g, g*.

Case 3. When incident diverging rays enter into a dense or rare medium.

Every thing being disposed as in the last experiment, I present the side of the box *A D*, *fig. 8, pl. 1*, when empty to the cone of light, so that it may coincide with the point of the cone *G*, which is where they begin to diverge, and will proceed on at *B C*, and form another cone directly opposed to the other, falling upon a white screen, placed at about four inches from the further side of the box. I measure this cone, and then fill the box with water ; the cone then becomes of an irregular shape ; the base on the screen is somewhat larger than it was before, but it is not so large at *B C* as it was before.

From hence we infer, that diverging rays become less diverging in passing from a rare into a dense medium ; and, on the contrary, that their divergence is increased by passing from a dense into a rare medium.

Let us consider the diagram, *fig. 18, pl. 1*, *K h, K h*, diverging rays meeting the refracting surface *L K*, do not proceed directly to *G G*, but
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are refracted, and approach the perpendicular, and go towards *g* and *g*, and are thus less divergent.

On the contrary, if they proceed from the dense medium, they are refracted, and go towards *l* and *f*, which render them more diverging, being twice bent at *h* and *g*, and thus forming an irregular cone.

Hence the image of a small object placed under water, is *one fourth nearer* to the surface than the object. And hence the bottom of a pond of water is $\frac{1}{4}$ *deeper* than it appears to a spectator above. An object at *E*, *fig. 18, pl. 1*, would appear at *e*. This may serve as a useful caution to those among you, who are not swimmers, and prevent your plunging unwarily out of your depths.

If you immerse a stick perpendicularly in water, until the immersed part appears of an equal length with the part above; then measure the parts, and they will be found to be to one another about as 4 to 3.

Hence also a fish appears higher than it really is, and the marksman, in shooting at it, must make an allowance for this false appearance, or he will miss his object.

If all the parts of an object, seen at some depth in the water, were equally displaced or altered, the image thereof would be exactly similar to the object it represents; for the figure depends on the respective position of the parts, which is not changed by a motion common to the whole. But this is not the case, if the object under water be of any considerable size; for those rays which come from the extremities that are most distant from the eye, fall more obliquely on the surface of the air, and are more refracted, and approach too near the refracting surface to preserve a total conformity of the image with it's object. Thus an eye at *K*, *fig. 18, pl. 1*, viewing at the bottom of the water a strait line, *g c d c g*, not only sees
thé

the whole line nearer to the eye than it really is, but the extremities $g g$ appear nearer than the other parts $d c$; thus it appears curved with the part towards the eye. Thus a strait leaden pipe appears at the bottom of the water to be curved, and the bottom of a flat bason deeper in the middle than at the sides.

Very thick dense mediums make objects appear larger than they really are; thus a fish appears larger in the water than when taken out, as do plants, stones, &c. To comprehend this, suppose for a moment, that g, g , *fig. 18, pl. 1*, are the extremities of an object seen at the bottom of the water, by the rays $g b, g b$. An eye placed in K judges of the size of the object by the angle $G K G$, larger than that of $g K g$; and the same happens with respect to every part of the object viewed through a denser medium than air.

Hence it is, that objects in a different medium from that where the spectator is, generally appear somewhat distorted.

OF REFRACTION AT A CONVEX SURFACE.

1. *When parallel rays pass out of a rarer into a denser medium, whose surface is convex:*

Before we proceed to make any experiments, or reason upon them, I must observe to you, that lines drawn from the center of a spherical surface are always considered, by mathematicians, as *perpendiculars* to that surface, and the angles they make with the angles of incidence are the angles of inclination. So that as light passing into a denser medium, is so refracted as to approach the perpendicular, or line drawn from the center of the spherical surface to the point of incidence; so in going from a dense into a rare medium, the rays separate from the same surface.

I place

I place the glass box so that the pencil of light falls directly on the convex glass at the end, and you see that as soon as I pour water into the box, the rays converge, and meet in a point: so that parallel rays, in this case, are rendered convergent; a circumstance that naturally arises from the laws of refraction, see *fig. 9, pl. 1*; for the parallel rays *bi, fg, fig. 19, pl. 1*, falling obliquely on the convex refracting surface, *g, E, i*, are bent towards the perpendiculars *ic*, or *gc*, (those lines being the perpendiculars to the points of the convex surface, on which the two given rays fall), and tend to unite at the axis *AB*. You will also take notice, that those rays which are furthest from the axis unite at points nearest the refracting surface; thus the ray *bi* falls upon the axis at *k*; but the ray *de* does not meet it, till it arrives at *D*; hence all those which are not too distant from the axis, may be considered as uniting in one point.

2. *When converging rays, passing out of a rare medium, fall upon the surface of a denser medium with a convex surface.*

I bring the box as before with the convex glass towards the ray of light; but in such manner, that the converging point of the pencil shall fall exactly on the center *A*, (*fig. 10, pl. 1*,) of convexity. I pour water into the box, and you find that there is no change in the situation of this point, because there is no obliquity of incidence.

Let us now try the effect with two other cones of light; one terminating at *b, fig. 11, pl. 1*, nearer the convex surface than its center; the other being beyond the center of convexity at *c, fig. 12, pl. 1*: mark exactly the place where the cone terminates in each of these cases, when there is no water in the box, and then fill it with water, and observe the difference in each case. You will

find the first cone, *fig. 11*, (where the rays tended to unite at *b*, before they reached the center of convexity) lengthened, and the point thereof terminating at a greater distance *B*; but the cone, *fig. 12*, (where the rays tend to unite at a point *c*, beyond the center of the convex surface) is shortened, terminating at *C*.

These experiments having made you masters of the fact, I shall now consider the three cases in a diagram. It is evident, that if *converging* rays fall upon a convex surface, they either tend to unite at the center of the convexity; or 2dly, their point of union will be nearer the refracting surface than that center; or 3dly, it will be beyond that center.

In the first case, the rays do not deviate: thus the rays, *ef, db*, *fig. 20, pl. 1*, converge at *c*, just as they would have done without the interposition of the refracting substance, because they do not possess the property necessary for refraction, namely, obliquity of incidence. For the rays *ef, db*, tending to *c* the center of the surface, may be considered as radii prolonged, and consequently as perpendicular to the convex surface.

In the second case, where the rays tend to unite nearer the surface than the center of convexity, they become less converging; for the ray, *ib*, *fig. 20, pl. 1*, which tends to *k*, is bent by the refracting surface, nearer the perpendicular *dc*, and is thus removed further from the surface, and joins the axis at *o*.

In the third case, where the rays tend to unite beyond the center of convexity, they become more converging: thus the ray, *gb*, *fig. 20, pl. 1*, tending to *l*, further from the convex surface *bbf*, than *c*, by approaching the perpendicular *dc*, is brought nearer the center, and joins the axis at *p*, where it would be met by another ray, falling upon the surface with the same degree of obliquity,

quity, but from the other side of the axis. This is the more common of the three cases.

3. *When diverging rays, passing out of a rare medium, fall upon a denser one with a convex surface.*

To shew what happens with these rays, we have only, as before, to place the box so that the diverging rays may fall upon the convex surface, and to receive the light upon a plane surface in the box, and to mark the size of the luminous circle formed thereon, before we pour any water into the box. This being done, I shall now fill our box with water, and you will perceive, that the luminous circle is considerably smaller than it was before, *fig. 13, pl. 1.* If you remove the box further from the point, from which the diverging rays proceed, the base of the luminous cone will still grow smaller, and at last become cylindrical; and if you go on removing it still further, they will converge in a point.

From these experiments we draw the following conclusion, That diverging rays, in passing from a rare medium into a denser with a convex surface, become less divergent, which may be carried so far, that they may become parallel, and even convergent.

The diverging rays *a m, a l, fig. 21, pl. 1,* meeting with the refracting surface *m b l*, do not proceed in strait lines to *f* and *e*, but are refracted towards the perpendiculars *e C, c C*, which gives them the directions *m g, l b*, much less divergent.

If the rays that fall on the refracting surface, as *d m, i l*, are less diverging than the preceding, they will be refracted so as to converge at *B*.

Let us now suppose the rays of light passing from a denser medium into a rare one, the dense medium being terminated by a convex surface on the side of the rare medium.

Parallel rays are thereby made to converge: thus the parallel rays de, gi , fig. 12, pl. 2, falling on the refracting surface, ei , instead of proceeding to fb , are bent further from the perpendiculars aC, bC , so as to converge at k .

Converging rays become more converging: thus the rays le, ni , which would, without refraction, go on towards m and o , are so refracted as to unite at p .

If the rays are diverging, the point from which they diverge is, 1st, either c , the center of convexity e, D, i ; or 2dly, a point r , between the center and the convex surface; or 3dly, a point q beyond that center.

In the first case, the rays Ca, Cb , are not refracted, because being radii they fall perpendicular to the convex surface.

In the second case, where the rays re, ri proceed from r , they do not go on toward s and t , but are refracted further from the perpendiculars aC, bC , and go on towards x and y , diverging more than before.

In the third case, the diverging rays qe, qi , become less diverging, and instead of proceeding towards z and z , they get closer together towards g and b , being refracted further from the perpendiculars aC, bC , and may be rendered parallel, or even convergent, according to the greater or less degree of divergence, when they arrive at the surface eDi .

OF REFRACTION AT A CONCAVE SURFACE.

1. *When parallel rays of light pass from a rare medium into a dense one, with a concave surface.*

One end of the box, fig. 5, pl. 1, is furnished with a glass with the concave surface outwards; this is now to be presented towards the cones of light.

In

In the present instance, let parallel rays fall on the concave surface. Having observed the size of the luminous circle formed by them within the box, fill the box with water, and you will find that the pencil of light is enlarged, and the luminous circle is much increased. See *fig. 14, pl. 1.*

That parallel rays necessarily in this instance become diverging ones, may be also rendered clear by a diagram. For the parallel rays *ab* and *de*, *fig. 1, pl. 2*, falling upon the concave refracting surface *e, b, b*, are by refraction made to approach the perpendicular *fC*, *gC*, which renders them diverging.

2. *When converging rays pass from a rare medium into a dense one, terminated with a concave surface.*

We proceed as in the foregoing experiment, observing where the converging rays terminate, before and after water is poured into the box, and that with different degrees of convergency.

You see, however great the convergency of the rays may be, that as soon as the water is put into the box, the cone is sensibly lengthened, *fig. 15, pl. 1.* With a less degree of convergence they are sensibly separated from each other; so that by altering the degree of convergency we render them either parallel or diverging. To view this in a diagram, you may consider the rays *ab, de*, *fig. 3, pl. 2*, tending to converge at *O*; these are by refraction made to approach the perpendiculars *fC* and *gC*, and thus do not unite till they come to *i*.

3. *When diverging rays pass from a rare medium into a dense one, terminated by a concave surface.*

Every thing being disposed as in the last experiment, remove the box so that the point where the rays meet, or cross, and begin to diverge, may fall upon the center of the concave glass; receive

the base of this cone on a plane placed at about seven or eight inches from the glass, measure the diameter, and fill the box with water.

Repeat the experiment with the concave glass nearer *C*, *fig. 16, pl. 1*, and afterwards further from it.

In the first case, the size of the circle is not enlarged, nor the cone of light altered. In the second, the base of the cone is smaller in the water than it was in the air. In the third, it is somewhat enlarged. See *fig. 16 and 17, pl. 1*.

In the first case, the rays undergo no alteration, because they have no obliquity of incidence, for *Cb* and *Ce*, *fig. 4, pl. 2*, are radii of the concavity, and continue their rout to *f* and *g*, as they would have done without the interposition of a refracting medium.

In the second, they become less divergent, for the two diverging rays *kb* and *ke*, instead of going to *d* and *b*, proceed to *a* and *e*, the refraction making them approach the perpendiculars *fC*, *gC*.

In the third case, which is the most general, the rays become more diverging; for *lb* and *le*, which tend towards *m* and *n*, are turned out of their way towards *i* and *o*, by approaching the perpendiculars *fC* and *gC*, and thereby become more diverging than they were before.

Let us now suppose that the rays of light pass from a dense medium into a rare one, and that the dense medium is terminated on the emergent side by a concave surface.

The parallel rays become divergent, for the parallel rays *de, gi, fig. 22, pl. 1*, in emerging from the concave surface *eDi*, do not continue their rout in straight lines towards *f* and *h*, but are carried towards *m* and *p*, by separating from the perpendiculars *Ca, Cb*, which renders them divergent.

If

If the rays are converging, they may be divided into three cases 1. When the point of convergency tends precisely to the center C , of the concavity eDi ; in this the rays ae, bi , do not suffer any refraction; because being the continuation of the radii Ce, Ci , of the concavity eDi , there is no point of oblique incidence.

2. When the rays qe, ri , tend to converge to the point n , nearer the concave surface eDi than it's center C , by separating from the perpendiculars Ce, Ci , they unite at o , and are thus rendered more converging.

3. When they tend to a point l , which is further from the concave surface than the center of curvature, they are rendered less convergent. For the rays se, ti , which tend naturally to converge to the point l , by separating from the perpendiculars Ce, Ci , unite in k , further off than they would have done without refraction, if they were only a little converging; on arriving at the concave surface eDi , the refraction may render them parallel or diverging.

The diverging rays Ee, Ei , diverging from the point E , which without the change from the medium would go on towards u and x , but by the refraction separating from the perpendiculars Ce, Ci , they are turned towards y and z , diverging more than before.

OF GLASS LENSES.

By a lens opticians mean a transparent body of a different density from the surrounding medium, and terminated by two surfaces, either both spherical, or one plane and the other spherical. And as the lenses for optical uses are generally made of glass, it is usual to call them *glasses*, with the addition of the use they are intended for; as a *magnifying*

rying glass, a spectacle glass, an object or eye glass of a telescope, &c.

Glass was probably the invention of some manufacturer, having nothing else in view but raising a fortune by his new manufacture: but from hence we are supplied with telescopes, microscopes, and prisms, which let us into secrets of nature unsuspected before, open to us the immeasurable grandeur of the universe, and bring us acquainted with animals to whom a spoonful of vinegar serves for a habitable world; thereby raising our idea of the *Author of nature*, by displaying the magnificence and wonders of his works. From hence likewise has proceeded gradually a more exact knowledge of the laws of attraction, the velocity of light, the existence of ether, and the extreme rarity of bodies. Thus the unlearned are often made to lend a helping hand to the contemplative in the prosecution of his science; and the man of this world instrumental in opening a larger field to our theology. Inventions are often termed *accidental*, and so indeed they are with respect to us; but *accidents* arise from certain causes which produce them, when it is proper they should be manifested, and are therefore to be referred to the *disposer* of all events.

A lens having one side plane and the other convex, is called a *plano-convex*; where one side is plane and the other concave, it is a *plano-concave*. A lens terminated by two convex sides, is called a *double convex*; a *double concave*, if terminated by two concave sides. A lens having one side concave, the other convex, is called a *concavo-convex lens*. See fig. 9, pl. 2.

From these definitions you will readily conceive, that there may be an infinite variety in the degrees of convexity and concavity; for a convex surface may be considered as forming part of a

sphere; and as the radius or diameter of this sphere is greater or less, the convexity will be different.

Hence when I say that the radius of the convex surface of a glass is three inches, I mean that it is the portion of a sphere whose radius is three inches. To render this subject clearer, here are a variety of lenses of different convexities; from these you see, that the smaller the radius is, the more the surface is curved, or the greater is its deviation from a strait line. On the contrary, the longer the radius the more it approaches to a plane; so that a plane surface may be considered as a convex surface of an infinite radius.

To explain the effect produced in the appearance of objects, by convex and concave lenses, we must distinguish two cases: 1. Where the object is at a considerable distance from the lens. 2. Where the object is near the lens. Before, however, I enter upon this explanation, it will be necessary to define what is meant by the *axis of a lens*. A strait line drawn perpendicular to both the sides of any lens is called the axis thereof;* the axis therefore passes through the center of the spherical sides; and as we represent the two surfaces by arches of a circle, you have only to draw a line through their respective centers, and it will represent the axis of the lens. Thus the center of the arch AEB, *fig. 23, pl. 2*, is at C, that of AFB at D, and the line CD is the axis of this lens; it is easy to see that the axis passes through the middle, and that no lens excepting a sphere can have more than one axis, because no other line can pass through the two centers C, D; and therefore all pencils are considered as oblique, excepting those whose foci are in the axis of the lens,
As

* If one of the surfaces be plane, the axis of the lens falls perpendicular upon the plane surface, and proceeds through the center of the spherical one.

As the axis is perpendicular to the two surfaces, it is plain from the nature of refraction, that a ray of light passing in this direction is not refracted, but goes on in the same direction in which it entered.

No ray that passes through the center *o*, *fig. 23, pl. 1*, of a lens is refracted; for the two tangents at *E* and *F* are parallel, and the effect is therefore the same as if the ray passed through a piece of glass whose sides are parallel.

I shall now proceed to consider the nature of double convex lenses. It is the property of these to make parallel rays converge to a focus; to increase the convergence of converging rays; to diminish the divergence of diverging rays, and that so much under certain circumstances as to render them parallel or convergent.

Let us consider *AB*, *fig. 24, pl. 1*, as a convex lens, whose axis is the line *OEFP*; and let us suppose that on this axis, and at a great distance from the glass, there is a luminous point or object *O* diffusing its rays in all directions; some of these, as *OM*, *OE*, and *ON*, will fall upon the glass, the middle one *OE* will not be refracted, but pass on in the direction *EFP*. The two other rays will be refracted and bent both at entering and going out, so as to meet at *J* somewhere on the axis, and then go on in the direction *JQ* and *JR*: the other rays between *M* and *N*, will be so refracted as to unite on the axis at the same point *J*. Thus the rays *OM* and *ON*, and those between them, which without the interposition of the glass would have followed their respective rectilinear directions, are so bent thereby as to follow other directions, and proceed as if they came from the point *J*; and an eye placed at *P* would be affected in the same manner as if the luminous point was at *J*; the glass *AB* forming an object at *J*, exactly representing

representing the object at O. Thus a considerable change is produced by the lens; a distant object, as O, is as it were transplanted and brought suddenly to J.

Let us now consider the effect produced on the rays of light, when the object is very distant from the lens. In *fig. 13, pl. 2*, MN represents a convex lens, OABTS the axis of the lens, OP a distant object situated on the axis; every point of this object diffuses rays in all directions; of these we are only concerned with those that fall upon the lens; and to render the subject clearer, I shall only consider three rays OA, OM, ON, proceeding from the point O; of these the first OA passing through the middle of the lens, its direction is not altered, but continues after it has passed through to go on in the line BTS, the axis of the glass. But the other two, OM, ON, are so refracted both at entering and quitting the lens, that they unite at T on the axis, from whence they again proceed in the directions MTQ, NTR, so that if an eye were to meet with them, they would produce the same effect thereon as if the object O had been situated at T. To distinguish, however, the true point O from the point T, the first is called the *object*, the other the *image* of that object, which image in its turn becomes also an object. When the object is at a considerable distance, the point T is considered as the *focus* of the glass. The following remarks on this point are necessary to be considered with attention.

1. When the point O, or the object, is at an infinite distance, the rays OM, OA, ON, may be considered as parallel to each other, and to the axis of the lens.

2. The focal point T, is a point behind the glass, where parallel rays falling upon that glass are united by the refractive power of the lens.

3. The

3. The focus of a lens, and the place where the image of an object situated in the axis of the lens, but at an infinite distance from the lens, is represented, are the same thing.

4. The distance of the point T from the lens is termed the focal *distance*.

5. Every convex lens has a particular focus; in some it is greater, in others less, which is easily found by exposing the glass to the sun, and observing where the rays unite.

6. Those lenses which are formed by the arcs of small circles, have their foci very close to them, and the focal point is further off in proportion as the surface or sides of the lens is formed by arcs of a longer radius.

7. In order to form a proper idea of the optical effect of any lens, it is necessary to know its focal distance.

8. When parallel rays AB, CD, *pl. 3, fig. 4*, fall upon a plano-convex lens DeR, and pass through it, they will be so refracted, as to unite at a point F behind it; this point is called the *principal focus*, and its distance Fe from the middle of the glass its *focal distance*, which is equal to *twice the radius*, or the diameter of the sphere's convexity.

9. When parallel rays AB, CD, *fig. 5, pl. 3*, fall upon a glass DeB equally convex on both sides, and pass through it, they will be so refracted as to unite in a point or *principal focus* F, whose distance is equal to the *radius* or semidiameter of the sphere of the glass's convexity.

The rays all cross the middle ray *de* in the focus F, and then diverge from it to the contrary sides; in the same manner as they converged in coming thereto. See *fig. 4* and *5, pl. 3*.

If another double convex lens *hg, fig. 5, pl. 3*, be placed in the rays at the same distance from the focus,

focus, they will be so refracted thereby as to proceed from it in a parallel direction, as at *bh*, *ge*, going on in the same manner as when they fell upon the first glass; but on contrary sides of the middle ray *De Fff*, for the ray *ABF* will go on in the direction *Fhb*, and the ray *CDF* in the direction *Fge*, and so of the rest.

To render the progress of the rays from an object through a lens, to the image behind, more evident, I have constructed a model in which the rays are represented by silk strings; that it may be more clear, the rays issue on from three points, and only three rays from each of these points.

In *fig. 9, pl. 4*, we have a figure of this model. *ABC* is the object placed somewhat beyond the focus of the convex lens *def*. The rays *Ad*, *Ae*, *Af*, flowing from the point *A*, are refracted into the directions *da*, *ea*, *fa*, meeting in the point *a*. The rays *Bd*, *Be*, *Bf*, proceeding from *B*, pass through the glass, and are so refracted as to unite at *b*. In the same manner those that flow from the point *c*, are conveyed and meet at *c*; at each of the points *a*, *b*, *c*, an image is formed of the respective points *A*, *B*, *C*. The same takes place with all the other intermediate points, by which means a perfect image of the object is formed.

I have already observed to you, that an object at an infinite distance has its image formed at the focus of a convex lens, provided the object be situated on the axis of the lens. I shall now proceed to consider nearer objects, but still situated in the axis; and you will find the nearer the object approaches the glass, the further the image is removed therefrom.

Thus let us suppose that *F, fig. 11, pl. 2*, be the focus of the lens *MM*, or place where the image of a distant object is represented. If the object be brought successively to *P*, *Q*, and *R*, the
image

image will be successively removed further from the glass to p, q, and r; the distance b r, &c. of the image always corresponding to that of the object A P, &c. Mathematicians have rules for calculating these distances, which would lead us too far into the intricacies of the science; it will be therefore sufficient to observe in general, that the more we diminish the distance of an object from the lens, the more that of the image is increased, which will be rendered plainer by an example, suppose of a lens of six inch focus; that is, if the object is at an infinite distance, the focus will be precisely at six inches; but when the object approaches the lens, the distance of the image will increase, as in the following table:

<i>Distance of the object.</i>	<i>Distance of the image.</i>
Infinite	6 inches
42	7
24	8
18	9
15	10
12	12
10	15
9	18
8	24
7	42
6	Infinite.

Although these numbers only agree with a lens of 6 inches focus, yet we may deduce the following consequences from them:

1. If the object be at an infinite distance, the image will be at the focus.

2. If the object be at double the distance of the focus from the glass, the image will also be at double the distance of the focus from the glass; thus in the foregoing example, when the object was at twice 6 or 12, the image was also at 12 inches.

3. When the object is at the same distance from

from the glass as the focus, the image is removed to an infinite distance on the opposite side.

4. In general the distance of the object and the image correspond reciprocally to each other; so that if the object be placed where the image was situated, the image will be found where the object was before placed.

5. If the lens AB collect in J, *fig. 24, pl. 1*, the rays which emanate from the point O, it will also collect the rays from the point J, and consequently the rays may be returned back in the direction in which they proceeded. This article is of considerable importance towards a thorough knowledge of the nature of lenses; thus for example, when I know that a lens has represented, at eight inches from it, the image of an object which is at 24 inches on the opposite side, I may conclude, that if the object be at eight inches, the image will be at 24.

When the object is situated at the focal distance from the glass, the image is suddenly removed to an infinite distance therefrom.

You inquire of me, what then becomes of the image, when the object is within the focal distance? can it be removed to a distance greater than infinite? this is impossible. The question, though not easily resolvable by metaphysics, does not embarrass a mathematician; for he proves that the image in this case passes to the other side of the glass, and is found of the same side with the object.

In every representation formed by lenses, there are two circumstances to attend to, one concerning the *place* where the image is formed, the other the *size* of the image. Having explained the first, I now proceed to consider the second. Let OP, *fig. 14, pl. 2*, be an object situated on the axis of the convex lens MN; find first the point I, where the rays proceeding from O, meet the axis; this done, we have to find where the other point P will be represented. To

To do this, consider the rays P M, P A, P N, which proceeding from P fall on the lens, and you see that the direction of the ray P A is not altered, because it falls upon the middle of the glass, but continues to proceed in the line A K S; it will therefore be somewhere in this line, as at K, that the rays P M, P N, will meet, and K will be the image of the other end of the object, the point K being determined by the place where a perpendicular to J O, from J, meets the line P S, and I K will be the image of the object. It is evident from this, that the image is *inverted*; so that if Q R was horizontal, and the object O P a man, in the image the feet would be upwards and the head downwards. It is also clear,

1. That the image is always small in proportion as it is nearer the lens, and larger the further it is removed therefrom. Thus O P, *fig. 15, pl. 2*, being the object, and M M the lens, the image will be smaller if formed at Q, than if it were formed at R, S, or T; that is, the image is larger the further it is from the lens.

2. There is a case where the image is precisely at the same distance from the lens as the object, which is when the object is placed at twice the focal distance from the lens.

3. When the image is twice as far from the glass as the object, it becomes double the size of the object, and in general the image is so many times larger than the object, as it exceeds it in distance from the lens: now the nearer the object is to the glass, the more the image is removed from it, and is consequently so much larger.

4. On the contrary, so much as the image is nearer to the glass than the object, it is so many times smaller than the object. If then the distance of the image from the glass was 1000 times less than that of the object, it would also be 1000 times smaller.

OF BURNING-GLASSES.

The sun, as we all experience, is the cause of heat at the surface of the earth; it's effects are most violent in those regions where it's rays fall with the least obliquity, for they arrive there with greater force, and in a greater quantity. Winds meet and destroy each other's forces, but the rays of the sun travel onward without impeding each other in their progress.

All substances feel the influences of the solar rays, not only in proportion as they strike against them more or less directly, but according also as they are fitted for their reception. For the rays, though they continue ever to operate, are restrained from acting too fiercely, by the nature and disposition of the bodies on which they fall, and their own equable diffusion. To give the rays greater power, they must be collected by art; and when their action is concentrated, they consume or change all bodies with inexpressible force.

One of the first uses to which convex lenses were applied, was that of collecting the rays of the sun, in order to set wood or other combustible matter on fire.

The sun is so far off, that we may consider every point upon it's surface as at an infinite distance, and may therefore suppose the rays emitted from each point to be parallel to each other; consequently all the rays from the sun that fall upon a convex lens, will by passing through the glass be made to converge, and unite in a focus behind it.

The *effect* of the rays of the sun, when they are thus collected, is the reason why the point where they are collected is called the *focus*: and the name, after it had for this reason been given to

this point, has been made use of as a general one to stand for any point, where converging rays meet, or to which they tend.

Every lens, whether convex, or plano-convex, will collect by refraction the rays of the sun dispersed over it's surface into a point, and thus become a burning lens. To understand this, let MN, *fig. 15, pl. 2*, represent a convex lens, receiving on it's surface the rays R, R, R, of the sun; these are refracted by the lens into a small luminous circle, which is the image of the sun.

As all the rays which fall upon the lens are united in it's focus, their effect ought to be so much more, as the surface of the lens exceeds that of the focus. Thus if a lens four inches broad collect the sun's rays into a focus at the distance of one foot or twelve inches, the image will not be more than 1-10th of an inch broad. The surface of this little circle is 1600 times less than the surface of the lens, and consequently the sun's light must be so many times denser within that circle; it is not therefore surprizing that it burns with a degree of ardour and violence exceeding any culinary fire.

That the ancients made use of burning-glasses, is evident from a passage in a play of *Aristophanes*, called the Clouds, where *Strepsiades* tells *Socrates*, that he had found out an excellent method to defeat his creditors, if they should bring an action against him. His contrivance was, that he would get from the jewellers a certain transparent stone, that was used for kindling fire, and then standing at a distance, he would hold it to the sun, and melt down the wax on which the action was written.

The most considerable of these glasses are those that were made by M. Tschirnhausen and Mr.

Mr. Parker. Tho' I have already mentioned * both to you, it may be worth while to enter into somewhat a larger detail of their effects. The diameter of that of M. Tschirnhausen was three feet, the focus was formed at twelve feet, and it's diameter $1\frac{1}{2}$ inch and weighed 160 pounds. To render the focus more vivid, it was collected a second time, by a lens placed parallel to the first, and so situated, that the diameter of the cone of rays, formed by the first lens, was exactly equal to the diameter of the second lens; so that it received all the rays, and the focus was contracted to eight lines, and it's force was increased proportionably.

The lens made by Mr. Parker, of Fleet-street, was formed of flint glass, is three feet in diameter, and when fixed in it's frame, exposes a clear surface of 2 feet $8\frac{1}{2}$ inches in diameter, weighs 212 pounds, focal length 6 feet 8 inches, diameter of the focus 1 inch. A second lens was used, which reduced the focus to half an inch.

I shall now recite some of the principal effects of that made by M. Tschirnhausen, having already noticed those of Mr. Parker's.

1. Every kind of wood caught fire in an instant, whether hard or green, or soaked in water.

2. Thin iron plates grew red-hot in a moment, and then melted.

3. Tiles, flates, and all manner of earth, grew red in a moment, and vitrified.

4. Sulphur, pitch, and all resinous bodies, melted under water.

5. Fir wood exposed to the focus under water, did not seem changed; but when broken, the inside was found burnt to a coal.

6. If a cavity was made in a piece of charcoal, and the substances to be acted upon were put in it, the effect of the lens was much increased.

7. Any metal whatsoever thus inclosed in the

O 2

cavity

* Vo'. i. p. 389.

cavity of a piece of charcoal, melted in a moment, the fire sparkling like that of a forge.

8. The ashes of wood, paper, linen, and all vegetable substances, were turned, in a moment, into a transparent glass.

9. The substances most difficult to be wrought on were those of a white colour.

10. All metals vitrified on a china plate, when the china plate was so thick as not to melt, and the heat was gradually communicated.

11. When copper was thus melted, and thrown quickly into cold water, it produced so violent a shock, as broke the strongest earthen vessels, and the copper was entirely dissipated.*

The experiments with a burning-glass, among other things, prove that fire is regularly diffused through all space, and perfect therein; and that when properly directed and put in action, it burns with a vehemence superior to any culinary fire. The fire was in the expanse before the glass was applied; and the surface by which it was collected and directed, only put that fire into action, which already existed.

Mr. Parker observed a violent *rotatory* motion in the rays at the focus, which rotatory motion became visible on a small mass of *gold* when melted; for it instantly assumed a motion round its axis, and that invariably *the same way as the earth moves* round its axis. The velocity of this motion was accelerated, if at any time the sun shone with greater brightness than before.

Though the heat of the focus was so intense as to flux gold in a few seconds, yet there was no heat

* When plates of copper are cast at a foundry, after the moulds have been well heated and dried, they wrap them round with blankets to prevent the access of any moisture, which would not only dissipate the metal, but blow up the works, and even overturn the house itself.

heat at a small distance therefrom; and the finger might be placed in the cone of rays, within an inch of the focus, without receiving any hurt. Mr. Parker had the curiosity to try what the sensation of burning at the focus was, and having put his finger there for that purpose, he says, it neither seemed like the burning of a fire, nor a candle, but the sensation was that of a *sharp cut* with a lancet.

You may, by means of the focal rays from this glass, char or burn a piece of wood to a coal in a decanter of water, and yet the sides of the decanter, through which the rays pass so very near the focus, will not be cracked, nor any ways affected; nor will the water be in the least degree warmed. The wood was afterwards taken out, and the rays thrown on the water; but no continuance of collected rays in this way, would either heat the water, or crack the glass; but if a piece of metal be put into the water, it soon becomes too hot to be touched, and communicating its heat to the water, makes it not only warm, but sometimes causes it to boil.

Though the water alone is not affected; yet when a little ink was poured into it, the water began to boil in a very little time.

OF THE SCIOPTIC BALL, OR CAMERA OBSCURA.

By *camera obscura*, opticians mean any darkened room, out of which all the light is excluded, but what comes through a lens upon a white screen properly placed, on which the objects seen without are depicted.

It is in general made in two different ways: one is, a large room or chamber, made as dark as possible, with the scioptric ball fixed in the window-shutter: the other is small, and made in various

cavity of a piece of charcoal, melted in a moment, the fire sparkling like that of a forge.

8. The ashes of wood, paper, linen, and all vegetable substances, were turned, in a moment, into a transparent glass.

9. The substances most difficult to be wrought on were those of a white colour.

10. All metals vitrified on a china plate, when the china plate was so thick as not to melt, and the heat was gradually communicated.

11. When copper was thus melted, and thrown quickly into cold water, it produced so violent a shock, as broke the strongest earthen vessels, and the copper was entirely dissipated.*

The experiments with a burning-glass, among other things, prove that fire is regularly diffused through all space, and perfect therein; and that when properly directed and put in action, it burns with a vehemence superior to any culinary fire. The fire was in the expanse before the glass was applied; and the surface by which it was collected and directed, only put that fire into action, which already existed.

Mr. Parker observed a violent *rotatory* motion in the rays at the focus, which rotatory motion became visible on a small mass of *gold* when melted; for it instantly assumed a motion round its axis, and that invariably *the same way as the earth moves* round its axis. The velocity of this motion was accelerated, if at any time the sun shone with greater brightness than before.

Though the heat of the focus was so intense as to flux gold in a few seconds, yet there was no heat

* When plates of copper are cast at a foundry, after the moulds have been well heated and dried, they wrap them round with blankets to prevent the access of any moisture, which would not only dissipate the metal, but blow up the works, and even overturn the house itself.

heat at a small distance therefrom; and the finger might be placed in the cone of rays, within an inch of the focus, without receiving any hurt. Mr. Parker had the curiosity to try what the sensation of burning at the focus was, and having put his finger there for that purpose, he says, it neither seemed like the burning of a fire, nor a candle, but the sensation was that of a *sharp cut* with a lancet.

You may, by means of the focal rays from this glass, char or burn a piece of wood to a coal in a decanter of water, and yet the sides of the decanter, through which the rays pass so very near the focus, will not be cracked, nor any ways affected; nor will the water be in the least degree warmed. The wood was afterwards taken out, and the rays thrown on the water; but no continuance of collected rays in this way, would either heat the water, or crack the glass; but if a piece of metal be put into the water, it soon becomes too hot to be touched, and communicating its heat to the water, makes it not only warm, but sometimes causes it to boil.

Though the water alone is not affected; yet when a little ink was poured into it, the water began to boil in a very little time.

OF THE SCIOPTIC BALL, OR CAMERA OBSCURA.

By *camera obscura*, opticians mean any darkened room, out of which all the light is excluded, but what comes through a lens upon a white screen properly placed, on which the objects seen without are depicted.

It is in general made in two different ways: one is, a large room or chamber, made as dark as possible, with the scioptric ball fixed in the window-shutter: the other is small, and made in various

ways, as that of a box, a book, &c. for the convenience of carrying it from place to place; whence it is called the *portable* camera obscura, and is useful to a young artist in taking the optical view of any proposed prospect.

It is by means of convex lenses that we obtain all the advantages that are derived from the camera obscura, which exhibits, in a most pleasing manner, all the objects seen without in their natural proportions, colours, and motions, as vivid and beautiful as life; which I shall shew you as soon as I have explained the nature of the instrument.

Let W, X, Y, Z, *fig. 6, pl. 2*, represent a darkened room or box, well closed on all sides, so as to admit no light but what comes through the lens o, whose focus is such that the image of the objects from without fall exactly on the wall.

In the diagram, to prevent confusion from too many lines, only three pencils are drawn, one from each of the extremes P, R, the other from the middle Q, of the object P Q R; and in these pencils there are only drawn the axis, and the two extreme rays.

But the rays that flow from any point (as P, for instance) upon the lens are innumerable, the whole conical space b P d being filled with them. These are all collected and united at the focus p, and there received upon the white paper, and are reflected by it in all manner of directions; so that to a spectator in the room, p is now, as it were, a real object, exactly similar to the physical point P, in proportion to it, as O p to O P, and p is of the same colour with P, because the rays flowing upon the lens from P are united at p, distinct and separate from the rays coming from other parts of the object.

Every other physical point of the object sends forth

forth it's cone of rays, which are united by the lens, orderly at p, q, r, and being there reflected by the screen, the image of the whole object is distinct and visible, like a picture drawn upon canvas; but much more lively and distinct than the best finished drawings of the greatest artist.

If the objects are very remote in proportion to the focal length of the lens, we shall have the pictures of those that are in the same neighbourhood, pretty distinct at the same time, though they are at the same distances from the lens; because in that case, the focal distances of the refracted rays differ only insensibly.

There will be as many foci upon the paper as there are radiant points in the object, from which the rays proceed; and these foci will be disposed in the same manner, in respect of one another, as the radiants. Those foci will be the most bright in which the most rays are united, and those will be the least bright in which the fewest rays are united.

Now the most rays will be united in those foci, which correspond to the radiants, from which the most light proceeds; and the fewest will be collected in those focal points, that correspond to radiants from which the least light proceeds. Therefore the light and shade upon the paper will be answerable to the light and shade upon the surface of the object.

When the rays from these foci are reflected by the paper, and enter the eye of a spectator, who looks at the paper, he will there see the picture, or likeness of that object; for the figure made up of these foci, will be like the figure of the object, because the focal points are disposed in the same manner, with respect to one another, that the radiants in the objects are. The light and shade upon the paper are every where answerable to the

light and shade upon the surface of the object. And the colouring of each particular part through the whole figure upon the paper, is the same with the colouring of the correspondent part in the object.

If the screen be moved nearer the lens, as to x , or farther from it, as to y , the picture will be confuted, because the rays proceeding from the next adjacent objects begin to interfere and mix together, as the rays from a will be mixed with those from P . The distinctness of the picture, we have observed, is entirely owing to the separation of the rays belonging to every point of the object upon their reception on the screen. If the screen be removed farther and farther from the focus, the picture will become more and more indistinct, and at length totally vanish, no one part being distinguishable from the rest; for all the rays, that proceed from the several points, must go to as many correspondent points to make a complete image of the object. *The brightness of the picture, when it's distance from the lens is given, is in proportion to the area of the lens.* The distinctness of the picture is not the same thing as it's brightness; nor is the confusion of parts the same thing as it's obscurity.

The picture may be distinct in all it's parts; the rays which come from one and the same point of the object, may be exactly collected into one and the same point on the paper; and yet, if but few rays should pass through the lens, the picture will be distinct, though faintly enlightened. Or, though the picture be confused, either by the screen being placed at an improper distance from the lens, or from any other cause, yet if many rays pass through the lens, the picture will be a bright one, notwithstanding it's confusion.

Hence you see that the brightness of the picture in every part depends on the rays that come

to that part, and that the picture will be bright or faint, in proportion as it is formed by more or fewer rays. Now the quantity of light, or number of rays that pass from any given object into the room, is greater or smaller in proportion as the hole through which they pass is greater or less, or as the area of the lens is greater or smaller.

The foot of the cross will be at *r*, and the top at *p*, for every object must be represented at the place where a line falls, drawn from the object through the middle of the lens; and consequently what is at the top will be represented at the bottom; objects to the right will be the left in the picture.

Why the image is inverted, is evident from a bare inspection of the figure; and it is also evident, that this inversion is not owing absolutely to the lens; for if that be removed, and the light be admitted through a small hole in the shutter, as you saw at the beginning of this Lecture, we shall have an inverted picture on the screen, though very imperfect when compared to that formed with the lens: the several pencils in both cases cross each other; but without the lens, the picture is very faint and confused; it is faint for want of sufficient light, so many rays from each point not being collected together; it is confused because the rays that proceed from the adjacent objects interfere and mingle together.

Let us now proceed to try the *scioptric ball*, or ox's eye. To use this, the windows of the room must be made to shut very close, and if there be any crevices they should be stopped, as we have done here, by nailing slips of cloth close over them; the sash is thrown up, and we have cut a hole in the shutter sufficient to let the ball move freely therein: to this we shall screw our instrument, which consists of three parts, a frame, a ball, and a lens. The flat side of the frame is to be placed
close

close to the window shutter; the frame consists of two parts, the flat board with a hole in it, and a screw, to which a ring may be screwed, by which the ball is confined; it moves with more or less ease, as this ring is screwed more or less tightly; the ball has a large cylindrical hole at each end, which is cut to a female screw for receiving a lens fitted in a cell. By the motion of the ball, the axis of the lens may be turned different ways; and the sphericity of the frame and ball prevents any light being transmitted between them. There are usually two lentes of different focal lengths; by using both together you obtain a third, having a shorter focus than either of the others. There is a paper screen, and a half polished glass, with proper supports, so that I may place either of them exactly in the focus, by moving them to and fro till the picture is distinct.

This instrument may be considered as a kind of *artificial eye*; the frame may represent a frustum of the orbit of the eye, and the wooden ball which is moveable every way therein the globe of the eye, moveable every way in it's orbit; the hole in the ball represents the pupil of the eye, the convex lens corresponds to the crystalline humour, and the screen to the retina; all which you will better comprehend when we come to explain the nature of vision. I fix the scioptric ball in it's place, and darken the room, and set the screen at a proper distance from the lens.

You see what a beautiful and lively picture of all the objects before the window is exhibited on the screen. It may with propriety be termed nature's art of painting. You have perspective here in perfection, or a just diminution of objects in proportion to the distances, the images being all in proportion to the respective apparent magnitudes of the objects seen by an eye at the hole in the window. The colouring here is just and natural, the
lights

lights and shades perfectly just, and the motions of all objects are perfectly expressed; the leaves quiver, the boughs wave, the birds fly, &c. as in nature, though much quicker, and in a lesser scene. From the camera obscura, the painter may learn his imperfections; he may see what he should do, and know what he cannot perform.

OBSERVATIONS ON THE SCIOPTRIC BALL.

All other circumstances being the same, the pictures of objects that are near, as within 5, 10, or 20 yards, are more vivid than those that are more remote. Universally, the pictures will be more distinct and pleasant, when the objects are at such moderate distances, in proportion to the focal length of the lens, as to exhibit small parts, as the features of a person's face, the tiles of a house, &c. If the light without is favourable, and the spectator has been some time in the dark, it is surprising how distinct and bold objects will appear, that are diminished at least 20 or 30 times; and a person may be known, when his features are no bigger than in that proportion. The lights and tints are then exquisitely delicate and perfectly just, and the relieves of objects surprizingly bold. A distant prospect appears perfect enough, but does not form so entertaining a picture.

All light should be excluded from it but what comes through the lens; for in proportion as the field about is darker, the objects will appear brighter, as the stars do in a dark night. The spectator himself should also be in the dark, at least while he looks at the picture; for by this means the pupils of his eyes enlarge; and as they enlarge, the apparent brightness of the picture will increase; and being free from extraneous light, the impressions on the retina will be more vivid and sensible. The objects should also be well enlightened, otherwise

wise the pictures will be dull, obscure, and no ways agreeable. You must therefore never exhibit ~~but~~ in a clear day, and it will answer best when the sun shines upon the objects; that is, if the prospect be western, the appearance will be best in the morning; if eastern, in the afternoon; if northern, about noon. A southern aspect is the worst of any for the camera obscura.

A proper aperture should be given to the lens; if the aperture be too small, the picture will be dark and obscure, and upon that account indistinct and unpleasant. If the aperture be too large, the picture will be indistinct, on account of the aberration of the extreme rays, of which we shall speak hereafter; and also because the picture will be too much enlightened by the adventitious light which enters the room, by which it is much obscured and injured.

The apertures will admit of some latitude, and may be more or less contracted, as the objects are more or less illuminated, or as they are nearer or farther from the lens. Mr. Harris says, that in a clear day, and the sun shining obliquely upon the objects, a lens of 18 inches focus does best with an aperture from 1 to $1\frac{1}{2}$ inch, according as the weather varies; when the weather was overcast, an aperture of $1\frac{1}{4}$ inch acted best; when the sun shone, a lens of 30 inches focus bore an aperture of $1\frac{1}{4}$, and would not bear more than $1\frac{3}{4}$ inch.

After every attempt to improve the picture, the apparent brightness will decrease nearly as the square of the focal length of the lens is increased. For this apparent brightness will be nearly as the density of the light in the picture, divided by the density of the adventitious light in the room. And whatever is the focal length of the lens, the density of the adventitious light will be nearly as the square of the linear aperture of the lens; and to
preserve

preserve the same density, the aperture must be as the focal length of the lens.

In some cases the breadth of the picture may be about $\frac{2}{3}$ of it's distance from the lens, and even more if the paper be made a little concave; that is, the picture may take in a field of near 40 degrees; but in most cases, when the field is so large, the picture will be more distinct in the middle than towards the extremes, and therefore you should seldom exceed an angle of about 20 or 30 degrees.

A glass having both it's sides ground flat, nearly parallel, and polished on one side, will exhibit the images of objects vastly more vivid and distinct, than by reflection from paper, &c. The rays are not so much dissipated in this case, as they are by reflection from the opaque surface; you are also less offended by extraneous light, as none is admitted but what falls upon the glass, and passes through it, and you may therefore have a good picture by a much deeper or shallower lens than you have on the paper.

The inverted position of the images in a camera obscura* is an imperfection; an inverted picture does not look near so pleasant as one that is erect, and a person cannot be known near so readily in an inverted picture, as after the same picture is set in it's proper position. But if you take a looking-glass, and hold it before you with the face towards the picture, and inclining downwards, the images will be erect in the glass, and appear with greater lustre than in the screen; or you may place a small mirror before or behind the lens, to inflect the rays before they come to the picture.

* In portable instruments this inversion is removed.

OF THE MAGIC LANTHORN.

The magic lanthorn has been generally applied to magnify small pictures in a dark room for the amusement of children: we shall shew you that it may be applied to more important purposes, by using it to explain the general principles of optics, astronomy, botany, &c.

The construction and theory of this instrument is very easy; it consists of a tin lanthorn with a tube fixed to the front; this tube consists of two joints, one of which slides into the other; by drawing the outermost joint out, or pushing it in, the tube may be made shorter or longer. At the end of this moveable tube a convex lens is fitted; the picture which is painted with transparent colours on glass, is placed in a groove made in the immoveable part of the tube, so that as the tube is lengthened or shortened, the lens will be either at a greater or less distance from the picture. In the inmost of the tubes, and as close to the side of the lanthorn as possible, is placed a thick convex lens, in order to cast a strong light from the lamp upon the object.

To be more particular; in the inside of the lanthorn, *fig. 2, pl. 3*, is a lamp *L*, whose light passes through the plano-convex lens *NKL*, and strongly illuminates the object *QR*, which is a transparent painting on glass, inverted and moveable before the lens *KL*, by means of a sliding frame in which the glass is fixed. The illumination is often increased by means of a concave mirror placed at the back of the lanthorn. If, when the object is properly illuminated, the lens *ST* be moved a little further from the object *QR* than it's focal distance, it will form a representation at a great distance on the opposite wall; and the image *VW* will be as much larger than the object *QR*, as the distance

distance ZO is greater than ZG . As the lens ST is moved farther out of, or pushed into the tube, the image VW will be smaller or larger, according to the distance of the opposite wall.

To render the picture distinct, no light should fall upon it but what passes through the lens, and for this reason the lanthorn must be used in a dark room. The lens should be very convex, so that the object may be very near it; for you have seen, that by so much as the object is nearer to the lens, will the image be at a greater distance from it, and consequently so much the larger; and since the image is inverted in order to make the picture on the screen upright, it is necessary that the object should be placed with the wrong end upwards.

FURTHER REMARKS ON THE PROPERTIES OF CONVEX LENSES.

Convex lenses are used for looking at objects: to comprehend this, we must consider their nature a little further. I have already told you, that when an object is very distant, the image is represented at the focus of the glass; and that the image is removed further from the lens, in proportion as the object approaches it; so that if the object is at the focal distance from the lens, the image is removed to an infinite distance. And for this reason, the rays ON, ON ; *fig. 8, pl. 2*, which fall upon the point O , are refracted by the glass, so that they become parallel to each other, as NF , and NF ; and as parallel lines may be considered as proceeding to an indefinite distance; and that the image is always where the rays, which proceed from the object, are united after refraction; in the case where the distance OA of the object is equal to the focus of the glass, the image is removed to an infinite distance. As it is indifferent whether

the parallel lines NF, NF , meet on the right or left hand, the image may be considered as being on either side, but at an infinite distance. From hence you will easily conclude, where the image will be found, when the object comes still nearer the lens than the focus.

Let OP , *fig. 10, pl. 2*, be the object: now as the distance OA thereof from the lens is less than the focal distance, the rays Om, Om , which proceed from the object, are too diverging to be rendered parallel by refraction; but continue divergent, as NF, NF , after they have passed through the glass, but much less so than before; so that by prolonging them on the other side the lens, they will meet somewhere, as at o ; consequently NF, NF , after refraction follow the same direction as if they proceeded from the point o , and an eye which receives these rays will be affected as if they came from o , and will imagine that the object of vision is at o : there will, however, be no image formed at o , and in vain would you apply a screen there to receive it.

But an eye at E receives the same impression as if the object OP existed at o . It is therefore important in such cases to know the size and place of the *imaginary* image op . With respect to the place, it will be sufficient to remark, that if the distance from the object AO was equal to the focal distance of the glass, the image would be at an infinite distance; but that as the object is brought to the lens, the more the imaginary image also approaches the glass, yet its distance always exceeds that of the object from the glass.

To illustrate this by an example; let the focal distance of the glass be 6 inches, and the following tables will give you the distances of the object, as well as the corresponding distance of the imaginary image op .

Distance

Distance of the object A O.	Distance of the imaginary image A c.
6	Infinite.
5	30
4	12
3	6
2	3
1	$1\frac{1}{2}$

The rule for finding the size of the imaginary image *op*, is easy and general. Draw a line *CPp*, through the extremity of the object, and *c* the center of the glass, and at *p*, where it meets the line *op*, perpendicular to the axis of the glass, you find *op* for the size of the imaginary image: from whence you see, that this image is always larger than the object; and that in proportion as it's distance from the glass exceeds that of the object from the glass: you also see, that the image is not inverted.

From these observations you will comprehend the use of convex lenses to persons who do not see near objects distinctly, but see well those that are at a distance; for by the help of these glasses they see near objects as if they were at a distance.

OF CONCAVE GLASSES.

As convex glasses cause the rays of light to *converge* and *unite*, so those which are concave make them *separate* and *diverge*; for which reason, if diverging rays fall upon a concave lens, they will diverge more after they have passed through it than they did before; and such rays as converge before their incidence, will, after their passage, converge less, their effect being directly contrary to that of convex lenses.

Let us consider their nature by a diagram, *fig. 12, pl. 2*, and *OP* as an object at a great distance, so that the rays *OM*, *OM*, may be deemed parallel. These falling upon the concave glass are thereby rendered more divergent, and go on in the directions *NF*, *NF*, as if they had proceeded from the point *o*, although they really proceed from *o*.

As the rays are deemed parallel, if the glass had been convex, *o* would have been the focus; but since there is no real concurrence of the rays, this point is termed the imaginary focus of the concave lens, and sometimes the point of *dispersion*, as the refracted rays seem to diverge from this point.

Concave glasses have, therefore, no real focal point; but one that is imaginary, whose distance *Ao*, however, is termed the focal distance.

When the object *OP* is at an infinite distance, the imaginary image *op* is represented at the focal distance of the concave lens, and on the same side as the object; but though this image is imaginary, the eye is affected in the same manner as if the rays proceeded from that point.

When the object is nearer the glass, the image *op* also approaches it; but so that the image is always nearer the glass than the object; whereas in convex glasses it is further from the lens than the object. To make this clearer, let us suppose, that the focal distance of the concave lens be 6 inches; the

Distance of the object <i>OA</i> .	Distance of the image <i>OA</i> .
Infinite	6
30	5
12	4
6	3
3	2
2	$1\frac{1}{2}$

The

The same rule as I gave you before determines the size of the image, by drawing a line from the center of the glass to the extremity of the object, which will pass by *p*, the extremity of the image; this image is not inverted. Indeed, it is a general rule, that the image is always upright when it is on the same side of the glass as the object. The figure shews you, evidently, that in concave glasses the image is always less than the object.

You may now see why concave glasses are of such use to short-sighted persons, or those who only see near objects distinctly; for they will represent distant objects to them in the same manner as if they were really very near.

A *meniscus* has the properties of a convex lens, when the inner radius is the greater, and of a concave when the inner radius is the smallest. If the two surfaces are concentric, it has the properties of neither; for the rays will then emerge parallel. If the radius of convexity be less than the radius of concavity, then the *meniscus* will have all the properties of a convex lens of the same focal distance. If the radius of the concavity be less than the radius of convexity, then the meniscus will have all the properties of a concave lens, whose focal distance is the same.

When any small object, or any point of that object, is seen by refracted light, it appears in the direction of that line, which the rays describe after their last refraction.

If the rays, that come from any small object, pass through a glass prism, of which *A C B*, *fig. 6*, *pl. 3*, is a section, the ray *D E* will be refracted towards a perpendicular, when it enters the prism, and will describe the line *E F*, and when it goes out of the glass it will be refracted from a perpendicular into the line *F G*; which line is the direction of it after it's last refraction, and the object

P 2

D will

D will be seen at L, instead of D; for in this and all other cases of the same sort, the picture of the object on the retina will be in the same place that it would have been if the eye had been really looking at an object placed at L; for the refraction gives the rays the same direction as if they had come originally from L.

From hence we understand why an object seen through a *multiplying glass*, or through a glass that is cut into different surfaces inclined to one another, appears, at one view, in many different places. If the object F is seen through the glass a b c d, *fig. 7, pl. 3*, by the ray A B, that passes through the surface c b, the object by the eye at A, will be seen at B, the ray D d passes through the surface c d, and when it is refracted comes to the eye in the direction A D, as if it proceeded from D, and therefore the object appears at D; and for the same reason through the surface a b, it appears at C; consequently there will be the appearance of as many objects as there are such surfaces on the glass, for each of them shews the same object in a different place. If such a glass be shaken before the eye, the objects on the other side will appear also to shake, as the situation of the ray by which it is seen will be varied with every motion of the glass.

In refracted vision, it is not the object itself we see, but the last image of it, which consists of all the imaginary radiants, or points, from whence the rays appear to diverge after their last refraction. That you may the better understand what I here mean by the last image, let *fig. 12, pl. 3*, be an object nearer to a convex lens than it's principal focus. The rays that diverge from any point b in this object will, by passing through the lens, be made to diverge less, and the imaginary radiant will be more remote than the real one. Thus the rays b g, b l, when

when they have gone through the lens, will not proceed strait forward in the lines gk , lp ; but will be refracted into the less diverging directions gm , ln , as if they had come from the imaginary radiant e , which is more remote than the real one b . The same will happen to the rays that come from a , or c , or any other point in the object; so that there will be somewhere behind the lens, as at d , as many imaginary radiants as there are real ones in the object, and these imaginary radiants taken all together compose the last image. And since all the rays fall upon the eye, as if they had diverged from this last image, the eye will be affected by the object abc , just in the same manner when it looks through the lens, as it would be without the lens, by an object in all respects like def , or as it would by the last image, if without the lens the last image could be made visible; and because the eye is affected when it looks through the lens, as if def was the object, and not abc , therefore we say, that it is not the object itself, but it's last image that we see.

This is universal; in refracted vision the eye is affected by the rays of light after refraction, as if they had come not from the object itself, but from it's last image, which consists of all the imaginary radiants from whence the refracted rays appear to diverge at the time they fall upon the eye.

TO FIND THE FOCAL LENGTHS OF LENSES BY EXPERIMENTS.

1. When the focal length of the lens does not exceed two or three feet, it may be found by holding the lens at such a distance from the wainscot opposite a window sash, that the image of the sash may be distinct upon the wainscot, and this distance may be considered as the focal length of the lens;

but if the focal length is long, you must compute the focus by the subsequent rule.

RULE.

Measure the distance between the lens and the object, and also from the image; multiply these distances together, and divide the product by their sum; the quotient will give the focal distance. Or, the square of the distance of the observed focus, divided by the distance of the object from the image, will give the excess of the observed focus beyond the true focal distance.

2. You may find the focus by making a candle the object. To do this, move the lens or the candle, and the paper for receiving it's image, so that when the image is most distinct the lens may be exactly between the other two; then halve the distance between the object or it's image, and the lens is the focal distance.

3. If a small hole about $\frac{1}{4}$ or $\frac{1}{8}$ of an inch be made in the window shutter of a darkened room, and a lens and piece of paper be held behind this hole at proper distances, the place where the image of the hole is distinctest, may be determined very critically, and from thence the focal length may be found by the foregoing rule.

4. By the sun's image. Place the lens so that it's axis may point as near as possible to the sun; then holding a paper opposite thereto, the burning point, or where the image of the sun is smallest, and the limb most distinct, is the focus. This method is sufficiently accurate for spectacle glasses and reading glasses, and such as are broad in proportion to their focal length; but will not answer for lenses of a long focus, unless they are sufficiently long to exhibit the solar spots; because in these cases the image is only a glare of light without distinctness;

distinctness; but the inconveniences may be removed by the following method.

5. Cover the lens with a piece of pasteboard or paper, and make two round holes therein at an equal distance from the edge of the lens, and on one of it's diameters. The lens being thus covered, point it's axis to the sun: now if a paper be held behind the lens, you will find the two circles or white spots produced by the two holes, gradually approach nearer to each other as the paper is moved further; at last they will coincide; and if the paper be moved still further, they will again separate. The distance of the paper from the glass when the circles unite being measured, gives the focal distance.

TO FIND THE FOCAL LENGTH OF A CONCAVE LENS.

Let the lens be covered with paper, having two small circular holes; and on the paper for receiving the light describe also two small circles, but with their centers at twice the distance from each other of the centers of the circles. Then move the paper to and fro till the middle of the sun's light, coming through the holes, falls exactly on the middle of the circles; that distance of the paper from the lens will be the focal length required.

TO FIND THE FOCUS OF A PLANO-CONVEX AND A PLANO-CONCAVE LENS.

By similar experiments you will find, 1. That the focus of a plano-convex, or of a plano-concave glass, is equal to a diameter of it's convex or concave surface, that is, of the whole sphere it belongs to.

P 4

2. That

2. That the focal distance of a double convex or double concave glass, of equal convexities or concavities, is equal to a semi-diameter of either of it's surfaces; and consequently that the focal distance of a glass of unequal convexities or concavities, will have an intermediate length between a diameter and semi-diameter, of that surface which is most convex or concave.

TO MEASURE THE FOCAL DISTANCE OF A GLOBE OF WATER AND OF GLASS.

Take a hollow globe of glass, or instead of it a thin round flask or decanter, and making a moderate round hole about an inch diameter, in a piece of brown paper, paste it on one side of the belly of the decanter; and having filled it with water, hold the covered side to the sun, that the perpendicular rays may pass through the middle of the water, and the emergent rays will be collected to a focus, whose nearest distance from the decanter will be equal to the semidiameter of the belly of it; as will appear by receiving the rays upon a paper, held at that distance. That this effect is owing to the water, and not to the glass, will be evident by emptying the decanter; for the light that passes then through the hole, will then be as broad as the hole itself, at all distances of the paper from the decanter. If a similar experiment be tried, with a solid globe or ball of glass, the distance of the focus from the nearest part of the ball will be one quarter of it's diameter.

TO FIND THE VERTEX OR CENTER OF A LENS.

Hold the lens at a proper distance from the eye, and observe the two *reflected* images of a candle made by the two surfaces. Move the lens till these

these images coincide, and that point is the vertex; and if this be in the middle of it's surface, the glass is truly centered, otherwise it is not.

The theory of real images is easily illustrated by experiment. For this purpose I shall draw a long line on the table, and place this convex lens at A, *fig. 7, pl. 2*, whose principal focus are at F and f. Now set off these distances on each side of A, and then set off the distance A F on the part of the line A B, marking the parts so set off, 1, 2, 3, 4, &c. On f D make f 1 equal to A f, and divide it into $f \frac{1}{2}$, $f \frac{2}{3}$, $f \frac{3}{4}$, &c. so that these parts be respectively equal $\frac{1}{2}$, $\frac{2}{3}$, $\frac{3}{4}$, &c. of f 1 or A f. This done, let us darken the room, and place a lighted candle over the division marked 2; the image of the candle will then be seen distinct but inverted, upon a paper held over the corresponding fraction on the other side at $\frac{1}{2}$. If you place the candle at 3 or 4, the paper for receiving the images must be held over $\frac{1}{3}$ or $\frac{1}{4}$, &c. So that if the candle be moved from 2 to an infinite distance, the whole motion of the image will be from $\frac{1}{2}$ to f; if the candle be at 1, the image will be at 1 on the other side. If the candle be brought nearer to F, the motions of the image and candle will be reciprocal to what they were before. But if the candle be placed any where between F and the lens, there will be no image formed.

OF THE DEGREES OF BRIGHTNESS AND DISTINCTNESS OF AN IMAGE.

Whatever be the shape and magnitude of the hole in the paper that covers part of a lens, the shape and magnitude of the image will be the same as when the lens is *uncovered*; because any small part of a pencil of rays has the same focus as the whole: but the brightness of the picture will be diminished,

diminished, in proportion as the hole in the cover is diminished; because the quantity of light which illuminates every point of a picture is diminished in that proportion.

A GENERAL VIEW OF THE PROPERTIES AND PHENOMENA OF SINGLE LENSES, DEDUCED FROM THE PRINCIPLES ALREADY ADVANCED. *

Let RF , *fig. 1, pl. 4*, be conjugate foci; P, p , the principal foci. By *conjugate foci* are meant two points so situated, that either of them being the *radiant*, the other will be the *focus*.

Then, 1. Parallel rays falling on one side of a convex lens, A , will be refracted to P , or p , on the other side, *fig. 1, pl. 4*.

2. Parallel rays falling on one side of a concave lens, A , *fig. 2, pl. 4*, will by refraction diverge from P , or p , on the same side.

3. In a convex lens, rays diverging from P or p , *fig. 1, pl. 4*, will emerge parallel on the other side.

4. In a concave lens, *fig. 2, pl. 4*, rays converging to p or P , will emerge parallel, going out on the same side.

5. In convex lenses, rays, *fig. 1, pl. 4*, diverging from R beyond P will converge to F beyond P , and the contrary.

6. In convex lenses, rays diverging from R , *fig. 3, pl. 4*, which is nearer P , will diverge from F on the same side with R .

7. In convex lenses, rays converging to F , *fig. 4, pl. 4*, will by refraction converge to R , nearer than P or f .

8. In concave lenses, rays converging to R , *fig. 2, pl. 4*, beyond P , will diverge from F beyond p , and the contrary.

9. In

* Emerson's Elements of Optics, p. 125.

9. In concave lenses, rays converging to F, *fig. 5 and 6, pl. 4*, nearer than p, will by refraction converge to R beyond F.

10. In concave lenses, rays diverging from R, *fig. 7, pl. 4*, nearer than p, will diverge from F nearer than p.

11. In concave lenses, rays diverging from R, *fig. 8, pl. 4*, nearer than p, will diverge from F nearer still than p.

A meniscus may be considered as convex or concave, according as the center of it's inner surface is further off or nearer than the center of the outward surface.

The length of an object is to the length of the image made by a lens, as the distance of the object from the center of the lens, to the distance of the image from the lens.

The area of the object is to the area of the image, as the square of the object's distance from the lens is to the square of the image's distance therefrom.

A convex lens magnifies an object, when it is nearer than twice the principal focal distance; but if further off, the object is diminished.

A concave lens diminishes an object in all cases.

If the object and it's image be both on the same side of the lens, the image will be *erect*; if they be on different sides, the image will be *inverted*.

When the object and image are on different sides of the lens, as the object approaches the lens, the image recedes from it; or if the object recedes, the image approaches.

If the object and image be both on one side of the lens, if the object moves towards the lens, the image also moves towards it; and the contrary.

In

In a convex lens, if the object be beyond the principal focus, it's image will be on the other side of the glass, and inverted. But if the object be nearer than the principal focus, the image will be on the same side of the glass, and erect.

The distance and magnitude of the image may be increased at pleasure, by causing the object to approach the principal focus.

In a concave lens, the object and image are always on one side of the lens.

The image made by a lens, becomes visible by placing the eye to receive the diverging rays going from the image, at a proper distance for distinct vision.

The image formed in the air by a lens, may not only be seen by the eye placed in the diverging rays, but it may also be seen upon a piece of paper placed at the focus.

If an object be placed at the principal focus of a lens, it's apparent magnitude at any place beyond the lens will be invariably the same, and equal to the apparent magnitude when seen from the center of the lens with the naked eye; so that the apparent magnitude of an object placed in the principal focus, will continue, whether the eye be moved nearer to or further from the lens.

The nearer the eye is to a lens, the more of the object appears; the farther off, less of it is perceived.

If the object be nearer than the principal focus, it's apparent magnitude grows less in going from the glass. If the object be further, the apparent magnitude is increased, when the eye goes further from the glass.

If the eye be fixed at the principal focus, the apparent magnitude of an object will be invariably the same, wherever the object is placed beyond the glass.

If

If the eye be fixed at a less distance than the principal focus, the apparent magnitude of an object is diminished, though by slow degrees, as it is removed from the lens.

If the eye be fixed at a greater distance than the principal focus, the apparent magnitude of an object is increased, as it is removed from the glass, till it comes to the conjugate focus in respect to the eye, and then it becomes infinite and confused, and begins to be inverted, and going further off is again diminished.

If the *eye and the object* be fixed, and a concave lens be moved from either of them to the other, the apparent magnitude of the object will decrease to the middle, and then increase again.

The brightness of an image formed by a lens from a luminous object, will be as the area of the lens directly, and the square of the distance reciprocally.

Though the brightness of the image increases with the area of the glass, the distinctness decreases; for it is only the rays very near the vertex that are refracted to a single point in the picture; those that are farther off deviate more and more, and thus render the picture confused.

Other phenomena of lenses will be considered in the course of these Lectures, which cannot be so well treated of till I have explained the nature of vision. You now begin to be acquainted with the properties of another subtil agent, whose particles are immensely minute, whose progress is astonishingly rapid, whose power and influence is beyond comprehension, maintaining an intercourse between systems, and diffusing numberless blessings in it's progress.

You have seen that a body, fit to reflect light and exhibit colours, when placed in the light, not only returns the rays of light that fall upon it, to the

the luminous body by which it was enlightened, but sends the picture of itself quite round the hemisphere in all directions, and to every point. Place a thousand, a million of such bodies near each other, each performs the same operation; the rays of light and their colours come instantaneous to the spectator's eye from each, without being disturbed or diverted in their passage by the numberless rays returned in different directions by other contiguous bodies. You have seen the vehemence with which this agent, whose parts are so wonderfully minute, acts when it's rays are collected by the burning-glass; that no terrestrial substance was capable of withstanding it's effects without being destroyed, or decomposed. Some of the effects produced by glasses of different figures, have been explained to you. You have also seen objects seemingly suspended in the air, where nothing was to be found that was sensible to the touch. In the camera obscura, you saw nature draw her own picture inverted, and in miniature: you saw a picture painted in a moment with a beauty, a vivacity, and softness of colours, that would make a landscape drawn by the first artists appear faint and languid: the picture of the camera was animated, the trees were agitated by the winds, the flocks bounded upon the lawn, and the sun-beams played upon the water: and you learnt that all these scenes depended upon the *refraction* of the rays of light, and were made acquainted with the laws of this refraction. In the xviiith Lecture you will see these laws applied to explain the nature of vision.

I cannot finish this Lecture without pointing out to you the analogy between the light of revelation, and the light of the heavens: * the similitude is such, that the language belonging to one may with

* Barton's Analogy of Divine Wisdom.

with great propriety be transferred to the other. As the *first knowledge of religion* was revealed by God; so the *first material light* was created by him. God, who alone is the living light of spirit, soul, and sentiment; the perpetual fountain of every stream of beauty and truth; HE said, LET THERE BE LIGHT; and instantly the internity of his ever-living light kindled up an externity of corporeal irradiation, that has it's effluence from him, and cannot beam but by him.

Though the solar light is perpetually shining forth, it falls very unequally on the world: in some places the day is equal to months, in others it's duration is only that of a few hours. It comes pure from it's source, but often meets with a foul atmosphere in it's course that obscures it, and changes it's direction. It shews many things different from what they are, but never misleads any one. It shines indifferently on all objects, is totally rejected by some, transmitted by others, bent and distorted by a third kind, and usefully imbibed by a fourth. It is the means of the knowledge of many things, yet it's own nature is but little known. It enlightens and enlivens the world, and promotes the vegetation of poison as well as of wholesome food.

Is not all this equally true of the light of revelation, as of material light? They that censure the one, may find pretences equally strong to traduce the other; and whatever objections the infidel points against the scriptures, will be found to apply equally strong against the manifestation of God in the visible course of nature.

LECTURE XVI.

OF CATOPTRICS.

AFTER having explained to you, as concisely as I am able, the laws of refraction, and the effect produced by these laws; I shall proceed to explain the doctrine of *catoptrics*, or that part of *optics* which treats of the *reflection of light*. You will here, among other things, learn how the figure of a man six feet high is seen in a glass mirror not above three feet; how in a convex mirror figures are reduced to a Lilliputian size, and in a concave mirror expanded to a gigantic size; wonders that the curious would wish to comprehend, and the inexperienced to examine.

Before *Newton* published his discoveries concerning the nature and properties of light, it was a principle generally received, that the rays of light were reflected, as other bodies, by striking on their solid and impervious parts, as you see a marble bound when struck upon the pavement. *Newton* taught mankind, that the particles of light are turned back before they touch the reflecting body, by some *power* which is equally diffused all over the surface of the body.

If, says he, the rays of light were reflected by impinging on the solid parts of bodies, their reflections from solid bodies could not be so regular as they are; for however polished the smoothest object may seem to our sight and touch, yet it is in fact one continued assemblage of inequalities. For in polishing glass with sand, putty, or tripoly, it is not to be imagined, that those substances can by grating and fretting the glass bring all it's least particles to an accurate polish, so that all their surfaces

faces shall be truly plane, or truly spherical, and look all the same way, or compose one even surface. The smaller the particles are, the smaller will be the scratches by which they continually wear away the glass until it be polished; but be they ever so small, they can wear away the glass no otherwise than by grating and scratching, and breaking the protuberances, and therefore polish it no otherwise than by bringing it's roughness to a very fine grain, so that the scratches and frettings of the surface become too small to be visible. From such a surface it cannot be supposed, that rays will be reflected with such uniformity as we usually observe: on the contrary it is highly probable, that if light were reflected by impinging on the solid parts of glass, it would be scattered as much by the most polished, as by the roughest surface.

It is therefore a *problem*, how glass polished by fretting substances, can reflect light in so regular a manner; and this *problem* is scarce otherwise to be solved, than by saying that the reflection of a ray is not effected by the reflecting body, but by some power of the body which is regularly diffused all over it's surface, and by which it acts upon the ray without immediate contact, so that it is reflected before it arrives at the surface.

A ray of light can fall but two ways upon a mirror, that is, either perpendicularly or obliquely; and experience has proved, that when light is reflected, the *angle of reflection is always equal to the angle of incidence*. Thus, suppose ab , fig. 25, pl. 1, to be the surface of a plane mirror, if a ray of light fc falls perpendicularly thereon, it is reflected in the same direction, making still a right angle with the mirror. If it falls in an oblique direction, &c. it is reflected in the direction cd , making with the mirror the angle of reflection $dc b$ perfectly equal to the angle of incidence eca .

I shall prove this to you by two experiments; first, I shall let a ray pass through a hole into a dark chamber, and fall obliquely upon a plane mirror; you will find, that at equal distances from the point of reflection, the incident and reflected ray will be the same height from the surface.

It is more accurately proved by the brass circle used before, *fig. 5, pl. 2.* I place the two radii at equal angles from the diameter: now if you look through the hole or sight down upon the center of the mirror, you will see the point of the other radii; which proves, that the ray which comes from that point is reflected from the center of the mirror to the eye, in the same angle in which it fell on the mirror.

This axiom, that *the angle of reflection is always equal to the angle of incidence*, holds good in every case of reflection, whether from plane or spherical surfaces, and that whether they are convex or concave.

All reflection is reciprocal. If the ray *ec*, after it has been reflected in the line *dc*, is turned back again in that direction, it will be reflected into *ec*; therefore if *dc b* is the angle of incidence, *ec a* will be the angle of reflection; and if *ec a* be the angle of incidence, *dc b* will be the angle of reflection.

This general law, that *the angle of incidence is always equal to the angle of reflection*, is the foundation of all catoptrics, and is sufficient for demonstrating all the phenomena thereof: other laws are only consequences deducible from this principle, or applications thereof to particular effects.

With reflected as with refracted rays, it is necessary that several rays should act at the same time, in order to make an impression on our eyes; these rays may be disposed differently with respect to each other;

other; they may be either parallel, convergent, or divergent; and the surface on which they fall, may be either plane, convex, or concave. Each of these circumstances we shall consider separately.

1. *Parallel rays falling upon a plane mirror are parallel after reflection.*

The parallel rays db , ca , *fig. 1, pl. 5*, are reflected from the surface ab to h and k , making the angle of reflection ibh equal to the angle of incidence $fb d$, and the angle of reflection gak equal to that of incidence $ea c$; and consequently from the principle of geometry the two rays db , ea , are parallel after reflection.

This may be proved also by letting two parallel rays (in a dark chamber) fall upon a mirror; and you will find that they retain their parallelism after reflection in every inclination of the mirror.

2. *When incident diverging rays are reflected from a plane mirror.*

The diverging rays db , ca , *fig. 2, pl. 5*, are reflected to h and k , and have the same degree of divergence at F as they would have had at E . If they had gone on in their first direction, the points at F and F are equally distant from the points of contact a and b ; therefore *the divergence of the rays is the same after reflection as before.*

3. *When incident converging rays falling upon a plane mirror are reflected therefrom.*

The converging rays db , ca , *fig. 3, pl. 5*, if the mirror were not interposed, would meet at E , but are so reflected from a and b , as to make the angles of reflection gbk , eah , equal to their respective angles of incidence $fb d$, $ea c$, and unite in F , a point at the same distance from a and b as the point E : *their convergence after reflection is therefore the same as before it.*

Let us now consider a *convex* surface, and you will find,

Q 2

1. That

1. *That parallel rays falling upon a convex surface are rendered diverging by reflection.*

2. *That converging rays, when reflected from a convex surface, become less convergent, and may be rendered parallel, or even diverging, according to the degree of convexity of the reflecting surface.*

3. *Divergent rays are rendered more diverging, so that a convex surface always tends to scatter the rays by diminishing their convergence, and increasing their divergence.*

As every curved surface may be considered as formed of an infinite number of small strait lines, which constitute the elements thereof; I shall, to render this subject more clear, represent a convex surface by two strait lines inclined to each other: by thus making the elements conspicuous, you will more readily comprehend why the rays of light, when reflected from a convex surface, take a different direction from what they had when they fell upon the mirror.

Let *b d*, *fig. 4, pl. 5*, represent a convex mirror, and *a b*, *c d*, *parallel* rays falling thereon; and because the angles of reflection *c b f*, *h d i*, are always equal, the rays are, as you see by the figure, rendered diverging, and proceed to *e* and *h*.

In the same manner the *converging* rays *a b*, *c d*, *fig. 5, pl. 5*, which if the mirror *b d* were not interposed would unite in *m*, have their direction so changed by reflection, that they proceed to and unite at *l*, much further from the points of contact *b* and *d*, than the point *m*; and you must perceive from the figure, that the inclination of the two elements *b d*, may be so increased as to render them parallel, or even diverging.

Thus the rays *a b*, *c d*, *fig. 6, pl. 5*, which without the interposition of the mirror would diverge but very little at *m*, are thereby rendered more diverging; so that they are much further apart at *l*, than at *m*.

We have now only to consider the direction of rays of light when reflected from a concave surface; and here you will find,

1. *That parallel rays are by reflection made converging.*

2. *That converging rays become more convergent.*

3. *That diverging rays become less divergent.*

A view of the diagrams is sufficient to prove the truth of these propositions.

Let *b d*, *fig. 7, pl. 5*, represent a concave mirror; the rays *a b*, *c d*, which were parallel before reflection, are by the laws thereof made to converge in *l*.

The rays *a b*, *c d*, *fig. 8, pl. 7*, which, without the interposition of the mirror, would unite at *m*, are thereby so reflected as to meet at *l*, nearer the points of contact *b d* than *m*.

Lastly, the rays *a b* and *c d*, *fig. 9, pl. 5*, which before reflection were divergent, converge after reflection meeting at *o*.

From the principles thus laid down, it is easy to see what will be the effect of mirrors, and to explain the principal phenomena which they occasion. By a *mirror*, or *speculum*, we, in general, mean any substance whose surface is sufficiently polished to reflect uniformly the greater part of the rays which fall upon it, and to exhibit an image of the objects placed before it. They are generally divided into *plain*, *convex*, and *concave* mirrors: there are besides these *conical* and *cylindrical*, *pyramidical* and *prismatical* mirrors.

OF PLANE MIRRORS.

It will be necessary here to remind you of what has been already mentioned; namely, that a pencil of rays emanating from any given point of

space, is the means by which the sight assures us, that a body exists at or in that point; it is plain, therefore, that we are liable to deception in that respect; for if the pencil be so affected by reflection (or refraction) as to proceed with different divergency or direction, that is, in the same direction as it would have proceeded if coming from some other point, the sense will refer the place of the object to the point, which is in the direction of the last course of the rays.

In a plane mirror *a b*, *fig. 10, pl. 5*, the image of an object *c* appears to an eye at *e*, behind the mirror in the direction *e g*, and always in the intersection *g*, of the perpendicular *c g*, and the reflected ray *e g*, and consequently at *g*, as far behind the mirror as the object *c* is before it. We therefore see the image in the same place, wheresoever the reflected ray be by which it is perceived; for as a plane mirror does not alter the relative position of the rays which fall on it, the diverging rays proceeding from *c*, are reflected towards the eye *e*, by the mirror *a b*, with the same degree of divergence, and have their imaginary point of union *g* at the same distance behind the mirror that *c* is before it.

For the same reason a plane mirror does not change, or alter the figure or size of objects; but the whole image is equal and similar to the whole object, and has a like situation with respect to one side of the plane that the object has with respect to the other; for the converging rays *K m*, *L n*, *fig. 11, pl. 5*, proceeding from the extremities of the object *K L*, and falling upon the mirror *a b*, are reflected towards the eye *e* with the same degree of convergence, and consequently shew the image *k l* under an angle equal to that by which the object would be seen from the point *i*, if the mirror were not interposed.

From

From what has been explained, it follows, that if an object *K L* is inclined to a plane mirror, it's image *k l* will be inclined thereto in a contrary direction.

If an object *A B*, *fig. 12, pl. 5*, be placed parallel to a plane mirror *C D*, and at the same distance therefrom as the eye *o*; the part of the mirror *C D*, on which the rays *A C*, *B D*, from the object fall, which are reflected to the eye, will be *one half* the length of *A B*. For the image being as far behind the glass as the object is before it, the rays *O G*, *O H*, are each divided at the middle of the mirror *C D*, and consequently where they only spread half as much, as they would do at double the distance. Therefore to see the whole of an object in a mirror, the length and breadth of the mirror must be half the length and breadth of the object. Hence if the length and breadth of an object be given, it is easy to determine the size of a mirror that will shew the whole of an object when placed at the same distance therefrom as the eye.

Hence a person viewing himself in a plane looking-glass, placed upright, will see his image complete in a part of the glass, whose length and breadth is equal to half the length and breadth of the corresponding parts of his own body; and this will be always the case at whatever distance he stands from the glass.

A spectator will see his own image as far beyond the speculum as he is before it; and as he moves to or from the speculum, the image will, at the same time, move towards or from him on the other side; but apparently with a double velocity, because the two motions are equal and contrary. In like manner, if, while the spectator is at rest, an object be in motion, it's image behind the speculum will be seen to move at the same rate. And if the spectator moves, the images of objects that are at rest will appear to approach, or

recede from him, after the same manner as when he moves towards real objects; plane mirrors reflecting not only the object, but the distance also, and that exactly in it's natural dimensions.

One principle is sufficient for explaining, with facility, the phenomena of objects seen in a plane mirror. It is this: *That the image of an object, seen in a plane mirror, is always in a perpendicular to the mirror joining the object and the image; and that the image is as much on one side the mirror as the object is on the other.* With the assistance of this principle and a little geometry, you may readily solve the principal questions that can be proposed on this subject.

The celebrated Archimedes, at the siege of Syracuse, is said to have destroyed the ships of Marcellus, by a machine composed of speculums. Since a plane speculum, in theory, reflects all the light, which is incident under the same affections with which it was incident, the rays of the sun coming from a vastly distant object may be considered as parallel, and will be reflected parallel to each other, and consequently will heat and illuminate any substance in the same manner as if the sun shone upon it. Two speculums, which reflect the light on the same substance, will heat it twice as much as the sun's direct light. Three will heat it three times as much; and by increasing the number of speculums, a prodigious degree of heat may be produced.

Though a plane speculum is supposed, in theory, to reflect all the light which falls upon it, yet in practice *almost half the light is lost* on account of the inaccuracy of the polish, and the want of perfect opacity in the substance of the mirror. Notwithstanding this, M. Buffon, in 1747, constructed a burning machine of this kind. It consisted of 168 plane mirrors, each 8 inches long, and 6 broad, so contrived that the focal distance

rance might be varied, and also the number of glasses, as occasion required. In the month of March, 1747, with 40 glasses he burnt a plank at the distance of about 70 feet.

OF CONVEX MIRRORS.

Convex mirrors spread or diverge reflected rays; they render parallel rays diverging; they diminish the convergence of converging rays; in some cases they render them parallel, and even divergent.

Let us suppose, an object *d e*, *fig. 13, pl. 5*, placed before a convex mirror *a b*. Of the two cones of rays proceeding from the extremities of the object, the rays *d p*, and *e p*, which if the mirror were not interposed would proceed to and unite at *p*, are reflected less converging on the line *f g*; the rays *d k*, *e l*, which would have converged at *m*, are reflected parallel; the two rays *d h*, and *e i*, which would have met at *c* the center of convexity, are reflected back on themselves, because of the perpendicularity of their incidence; they are, however, diverging; and all the rays proceeding from points beyond the two last will be reflected more diverging.

In *convex mirrors*, as well as those that are plane, the image always appears erect, and behind the reflecting surface, but differs from it in other respects; for, 1. *The image, in a convex mirror, is always smaller than the object*, and the diminution is greater in proportion as the object is further from the mirror. This will appear clear to you on reflecting on the properties of a reflecting convex surface, that incident converging rays are thereby rendered less convergent: thus let *C D*, *fig. 14, pl. 5*, be an object placed before a convex mirror *a b*, two rays *C e*, *D d*, proceeding from

from the extremities of the object, these, if the mirror were not interposed, would converge at *f*; but are reflected by the mirror less converging, so as to meet at *i*, thus forming a more acute angle; the object appears smaller than it would have done if it had been viewed from the point *f*. 2. *The image does not appear so far behind the reflecting surface as in a plane mirror.* Let *G*, fig. 15, pl. 5, be a point of any object, from whence a diverging cone of rays proceeds, and falls upon the mirrors; these rays are reflected more diverging, and have consequently their imaginary focus, or point of union *g*, much nearer, by which means the image appears to be nearer the reflecting surface than the object; and this effect increases in proportion to the convexity of the mirror. Concave mirrors have a real focus, convex mirrors only a virtual focus, and this focus is behind the mirror, distant therefrom half the radius of it's convexity.

The image of a strait object, not too small, and placed parallel or oblique to the mirror, is seen curved in the mirror, because the different points of the object are not all at an equal distance from the surface of the mirror. The point *o*, fig. 14, pl. 5. for example, of the object *d e* is nearer than the rest to the surface of the mirror, the extreme points *d e* are more distant; they will of consequence be represented behind the mirror, at distances proportional to those at which they are placed before, whence it becomes bent or curved.

OF CONCAVE MIRRORS.

I have already shewn you, that it is the property of concave mirrors to collect the rays of light they reflect, converging parallel rays, increasing the convergence of those that are already converging, diminishing the divergence of diverging

verging rays, in some cases rendering them parallel, and even convergent. These effects are all in proportion to the concavity of the mirror.

The point where the rays unite is called the *focus* of the mirror; but this focus is not the same for all kinds of incident rays. Parallel rays *a b*, *d e*, falling upon a concave mirror *m o*, are reflected so as to unite at *F*, *fig. 16, pl. 5*, which point is distant from it's surface $\frac{1}{4}$ of the diameter of the sphere of the mirror; this point is called the focus of parallel rays, or *true focus of the mirror*. Converging rays, such as *f g*, *h i*, are reflected more converging, and unite at *K*, between the focus of parallel rays and the mirror. Lastly, diverging rays proceeding from a point further from the mirror than the true focal point, as *R m*, *R o*, are reflected converging, and meet at a point *P*, further from the mirror than the focal point of parallel rays. But if the point *K*, from which the diverging rays proceed, is nearer the mirror than the point *E*, they are diverging; that at *g* would proceed to *f*, and that at *i* towards *h*.

The *focus* therefore of parallel rays is at one fourth the diameter of the sphericity of the mirror. The focus of converging rays is nearer the mirror than that of parallel rays; but the focus of diverging rays is more distant.

Plane and convex mirrors exhibit their images as if behind the mirror and erect. The effect of concave mirrors is different; they only shew the image behind the mirror and erect, when the object is placed between the mirror and the focus of parallel rays, and then the image is larger than the object. Let *A B fig. 17, pl. 5*, be an object placed before a concave mirror *E F*, but nearer than the focus of parallel rays: the two rays *A e*, *B f*, from the extremities of the object, if the mirror were not interposed, would converge in *d*; but are reflected
more

more converging, and unite at D, and there form a larger angle, and of course exhibit the image a b larger than the object.

This image appears further from the back-side of the mirror than the object does from the fore-side. Let A, *fig. 18, pl. 5*, be a point of any object placed nearer the mirror than it's focus, and from which a cone of diverging rays proceeds; these will be reflected less diverging, and therefore have their imaginary focus *a* further off, and consequently the image will seem at a greater distance behind the mirror, than the object is from the front of it.

But if the object be further from the mirror than F, for example, at *e*, *fig. 18, pl. 5*, the rays *e b, e d*, diverging but little, are reflected convergent, and exhibit the image at E; so that if the eye *o* recedes far enough to receive the diverging rays from E, it will perceive the image at E between itself and the mirror. The reason is plain; every enlightened point of an object becomes visible by means of a cone of diverging rays proceeding therefrom; we cease to see it if the rays become parallel or converging, which happens when the object is further from the mirror than it's focal point F; the eye therefore must recede, till the rays, having crossed, become divergent.

This image is always inverted, as *ba*, the image of *BA*, *fig. 19, pl. 5*; for we cannot see the whole of an object *AB*, unless diverging rays from it's extremities fall upon the eye; and this cannot in the present instance take place till after these rays have crossed between the object and mirror, by which of course they are inverted.

I shall endeavour to illustrate further, by a diagram, the theory of the foci of rays reflected by a spherical speculum. Through the center O of the speculum A, *fig. 5, pl. 6*, draw an indefinite line
B D;

BD; bisect O A in F; from the points O and A, divide the lines O B, A D, into parts each equal to O F or F A, marked by the figures 1, 2, 3, 4, 5, &c. And from F, take on each side F 1, F $\frac{1}{2}$, F $\frac{1}{3}$, F $\frac{1}{4}$, &c. each equal to the whole, or $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. of F O, F A. Now, if in the line O B, the point 1 or 2, 3, 4, &c. be the focus of incident rays, the correspondent point 1, or $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. in the line O F, will be the focus of the reflected rays. And *vice versa*, if the last be the foci of incidence, the former will be the foci after reflection. In like manner, if 1, 2, 3, 4, &c. in the line A D be the foci of incidence, 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. will be the foci of reflected rays; and *vice versa*: so that the focus of incidence and reflection unite in O and A: and their motions from O and A towards B and F in the one case, and towards D and F in the other, are exactly similar, F being the focus of parallel rays in both cases.

If in a dark room a lighted candle be held farther from a concave speculum than it's principal focus F, as suppose at 2, it's image will be seen distinct, but inverted upon a white paper, held at the corresponding point $\frac{1}{2}$. And if the candle be moved to or from the speculum, so as to retain the distinct image thereof, you will obtain an ocular proof of the theory of the foci of incident and reflected rays; when the candle is at o, the paper will be there also. But as the image of an object between F and a concave speculum, or any where before a convex one, is on the other side of the speculum, in either case, the experiment of the candle and the paper cannot take place.

The appearance of the image in the air between the mirror and the object, has been productive of many agreeable deceptions, which, when exhibited with art and an air of mystery, have been very successful, and a source of gain to many of our public *showmen*. I was well pleased at one of these

these exhibitions, by a man in Bond-street, where a death-head and other objects were exhibited in this manner, in such a way as to surprize the ignorant, and yet not disgust those who were better informed.

If you place yourself before this concave mirror, but farther from it than the focus, you will see an inverted image of yourself in the air between you and the mirror, but you will find the image of a smaller size than yourself. If you hold out your hand towards the mirror, the hand of the image will come out towards your hand, and when at the center of concavity be of an equal size with it; and you may shake hands with this aerial image. If you move your hand farther, you will find the hand of the image pass by your hand, and come between it and your body; if you move your hand towards either side, the hand of the image will move towards the other, the image moving always contrariwise to the object. All this while, those who are by-standers see nothing of the image, because none of the reflected rays that form it enter their eyes. To render this effect more surprizing and more vivid, the mirror is often concealed in a box.

This pleasing and simple experiment has been exhibited as an illustration of the Newtonian doctrine of space. The experiment shews, that by an image formed in the air, at a certain distance between a concave speculum and a person looking into it, *extension* and *form* become an *object of sense*, where there exists neither solidity nor sensible resistance. But this does not prove, that an image can be formed in a vacuum, in empty space, or where there is no matter, unless it can first be proved, *that there can be no matter where we are not sensible of resistance*. For on the contrary, it may be inferred from this phenomenon, that those spaces,

spaces, which in a loose and incorrect sense we call *empty*, are as *full* of matter as those in which we find the most solid matter: for as our corporeal senses can be only affected by matter, they are certainly infallible standards for determining where matter is; so that you may be as assured of a fullness of matter, where you *see* any thing though you cannot *feel* it, as you would be certain there was matter where you *felt* it, though you could not *see* it, or though it were of the nature of that matter to be invisible. All kinds of *reflected images* shew, that wherever an object can be formed to impress the senses of sight, there must be as great a fullness of matter as in the original object, from whence the image was carried to those spaces where it is again renewed.

Mr. Ferguson mentions two pleasing experiments to be made with a concave mirror, which you may take an opportunity of trying at leisure. If a fire be made in a large room, and a smooth mahogany table be placed at a good distance near the wall, before a large concave mirror, so that the light of the fire may be reflected from the mirror to it's focus upon the table; if you stand by the table, you will see nothing but a longish beam of light; but if you stand at some distance, as towards the fire, you will see an image of the fire on the table, large and erect: and if another person, who knows nothing of the matter before hand, should chance to come into the room, he would be startled at the appearance, for the table would seem to be on fire, and by being near the wainscot, endanger the whole house. There should be no light in the room but what proceeds from the fire.

If the fire be darkened by a screen, and a large candle be placed at the back of the screen, a person standing by the candle will see the appearance of a fine large star or rather planet upon the

table, as large as Venus or Jupiter; and if a small wax taper be placed near the candle, it will appear as a satellite to the candle; if the taper be moved round the candle, the satellite will go round the planet. Numerous and astonishing are the phenomena that may be produced by concave mirrors: one or two more I shall exhibit, your own ingenuity will enable you to vary them.

Stand up on this stool, and tell me what you see on the pot near the partition. A bunch of flowers. Put out your hand, and lay hold of them. They have evaded your endeavours, and you find that you attempted to grasp a shadow. The sense of sight is certainly subject to the greatest illusion, and this experiment is one among many instances. To explain the mystery, go behind the partition, and you will find that I have placed a mirror exactly facing the hole in the partition. There is also an Argand's lamp, so placed as to throw a strong light on the object, without throwing one on the mirror. The bunch of flowers is situated beneath the aperture in the partition, but inverted so as to receive the light from the lamp. The space between the back part of the partition is painted black to prevent any reflection of light from falling on the mirror. The rest is exactly similar to what you have already seen, and what has been already explained.

Take a glass bottle, fill it partly with water, and cork it in the common manner; place this bottle opposite a concave mirror, and beyond it's focus that it may appear reversed; then place yourself still farther distant than the bottle, and it will be seen in the air inverted, and the water which is actually in the lower part of the bottle will appear to be in the upper.

If you invert the bottle while before the mirror, the image will appear in it's natural erect position, and the water will appear in the lower
part

part of the bottle: while it is in this inverted state, uncork the bottle, and while the water is running out, the image is filling; but as soon as the bottle is empty, the illusion ceases. If the bottle likewise be quite full, there is no illusion. The remarkable circumstances in this experiment are, 1. Not only to see an object where it is not, but also where it's image is not. 2. That of two objects which are really in the same place, as the surface of the bottle and the water it contains, the one is seen in one place, the other in another, &c. It is supposed that this illusion arises partly from our not being accustomed to see water suspended in a bottle with the neck downward, and partly from the resemblance there is between the colour of air and the water.

As parallel rays which fall on a concave mirror are reflected so as to unite at a focus; and as the sun is so remote, that the rays of each beam may be considered as parallel, they will converge to the principal focus of the mirror, and the heat produced by this means will be sufficient to set fire to such bodies as are placed before the mirror at the principal focal distance, that is, half a semidiameter of the mirror's concavity. The different degrees of heat at the focus of different concave mirrors, is estimated in the same manner as we have already estimated the power at the focus of a convex lens.

The ancients made use of concave mirrors to rekindle the vestal fires. Plutarch, in his life of Numa, says that the instruments used for this purpose, were dishes, which were placed opposite to the sun, and the combustible matter placed in the center, by which it is probable he meant the focus, conceiving that to be at the center of the mirror's concavity.

You have, no doubt, long since perceived that there is a great resemblance between the properties of *convex lenses* and *concave mirrors*. Convex

lenses and concave mirrors form an inverted focal image of any remote object by the convergence of the pencil of rays.

Concave lenses and *convex mirrors* have also considerable resemblance in their properties; they in general form an erect image in the virtual focus, by the divergence of the pencil of rays.

In those instruments, as telescopes, whose performances are the effects of reflection, the concave mirror is substituted in the place of the convex lens, and the convex mirror may be used instead of the concave lens; but their dispositions with respect to each other must necessarily differ from those of lenses, on account of the opacity of the one, and the transparency of the other.

The following curious experiments by Mr. King,* are too important to be passed over; besides which, they have an intimate relation to some of the subjects already treated. Mr. K. placed a common size candle at the distance of six feet from a concave glass mirror, two feet and an half in diameter; and at the distance of seventeen feet three inches, he placed a second glass mirror, two feet diameter; and in the focus of this glass, at two feet six inches, he placed the bulb of a thermometer, graduated with Fahrenheit's scale. In five minutes the quicksilver in the thermometer, though at 25 feet 9 inches from the candle, rose 8 degrees, namely, from 60 to 68; on being removed from the focus, it fell again to 6. That it's rise was not occasioned by any additional warmth in the room was certain, because another thermometer which was in the room did not rise at all in the interval. The alteration of the height of the quicksilver was therefore solely owing to the concentration and convergency of the rays of the light of the candle at the focus.

He

* See Morsels of Criticism, by E. King, Esq.

He then removed the candle, and, under the same circumstances, placed a little wire grate 4 inches in diameter, containing 3 pieces of lighted charcoal, and causing them to burn bright by blowing a common pair of bellows, the thermometer was again placed in the focus; in six minutes it rose 19 degrees, from 60 to 79, although the heat of the room was no way increased by the experiment, as it was very large. One remarkable circumstance attended this experiment, which was, that there was very sensibly to be perceived a small increase of heat the whole way from the surface of the second mirror to the focus; whereas when the rays of the sun are made use of, no such increase of heat at all is ever perceived within the conical convergency.

After making several similar experiments, all of which concurred in proving that the effect was produced by the rays of light and heat from the ignited bodies, Mr. K. placed a tea urn of boiling water in the place of the charcoal, at the distance of 6 feet from the first mirror, and placing the thermometer in the focus of the second mirror, in the space of five minutes the quicksilver rose one degree, which was even more than could be expected; in the next five minutes, the thermometer advanced one degree more, and yet the other thermometer in the room remained stationary; in another five minutes, the steam cooling, the thermometer began to descend, and in five minutes more the quicksilver fell one degree.

The result of these experiments is clear and obvious: That fire is in a degree subject to the same kind of *reflexibility* and *refrangibility* * with the rays of light.

R 2

If

* For a convex lens interposed between the mirror and the focus, augmented the effect of heat.

If a luminous body be placed in the focus of a concave mirror, it's rays will be reflected in parallel lines, and will therefore strongly enlighten, at a great distance, a space of the same dimension with the mirror. If the luminous object be placed nearer than the focus, it's rays will diverge, and consequently enlighten a larger space. It is on this principle that reverberators are constructed.

But few articles on this subject remain to be discussed. I have only to shew you how to find the principal focus of these mirrors, and then give you a concise view of the properties we have already investigated, and an explanation of the various phenomena of pictures viewed in a concave speculum.

TO FIND THE FOCAL LENGTH OF A SPHERICAL SPECULUM.

1st. *For a Concave Speculum.*

Place the speculum so that it's axis may be nearly towards the center of the sun. If the speculum be concave, find the burning point; or receive the image upon a white piece of paper; and the distance between the focus so found, and the vertex of the speculum, is the focal length. Or, cover the speculum with a sheet of opake paper, in which make two or more holes, and observe where the beams of light reflected from these holes unite, and this will be the focal distance. Or, lastly, place the speculum at the end of a long table, in a vertical position; place a candle at the opposite end of the table, so that it's flame may be opposite to the vertex of the speculum; then take a piece of white paper, and having fixed it to a stick, place the stick in the socket of a candlestick, so that the paper may be supported at about the same height with the candle; then move the paper or the
candle

candle to and fro, till the image of the candle on the paper is exactly over the candle itself, and the point of coincidence is the center of the speculum.

2. *For a Convex Speculum.*

Stick two round opake patches thereon, and hold a white paper parallel to the speculum, and observe where the shades of the patches fall upon it, as at G, H, *fig. 1, pl. 6*; measure exactly the distance AG, and the distance betwixt the centers of the shades G, H, and between the centers of the patches; then $GH - AD (= e H)$ to AD, so is AG $(= De)$ to AF, the distance required.

Or, cover it with paper, having two pin holes made, one near each edge of the mirror; expose it to the sun, holding another paper before it, having a hole large enough to let the solar rays pass through to the two pin holes. You will see two white spots of reflected light on each side the hole; move the paper backward and forward, till the distance of the spots be twice the distance of the holes in the cover, and that distance of the paper from the lens is the principal focus.

GENERAL PROPERTIES OF SPECULUMS.

To see the image of an object made by any spherical speculum, the eye must be placed in the diverging rays, facing the image, and at a proper distance for distinct vision.

If the eye be placed near the speculum, in the converging rays before they reach the image, it will perceive the image of the object beyond the glass, and at the same distance nearly as the object is before it, and of the same magnitude.

If an image be viewed with both eyes, placed very near the image, and in the diverging rays,

either it will not be seen at all, or it will appear double; for the axes of the eyes cannot both be directed to an object extremely near.

Though an eye cannot see an image in the air, except it be placed in the diverging rays; yet if that image be received on a white paper, it may be seen in any position of the eye. For the rays reflected from the mirror to the image and beyond, flow but in that one direction; but when the image is received on white paper, the rays are reflected in every direction.

If the eye be moved whilst it views the image, the image will appear to be moved; for rays will come successively to the eye from different points of the speculum.

If an object be placed in the principal focus of a concave speculum, it's apparent magnitude to the eye, at any place whatsoever, will be invariably the same, and equal to the apparent magnitude to the naked eye, when seen from the center of the speculum. Consequently the apparent magnitude of an object placed in the principal focus, will always continue the same, however the eye is moved backward or forward from the speculum.

The nearer the eye is to the speculum, the more of the object appears, and *vice versa*.

If the object be nearer than the principal focus, it's apparent magnitude grows less in going from the speculum; if it be further off, it increases.

The apparent magnitude of an object will be invariable wherever it be placed, *if the eye be at the principal focus*.

When the eye is at a less distance than the principal focus, the magnitude of the object decreases as it is moved from the speculum.

When the eye is fixed at a greater distance than this focus, the apparent magnitude of an object increases in going from the speculum till it arrives

arrives at the conjugate focus; then it is all confusion. Afterwards it diminishes again, and is inverted.

A face in going from a concave decreases to the principal focus, and then increases.

OF PICTURES SEEN IN A CONCAVE SPECULUM.

If a picture, drawn according to the rules of perspective, be placed before a concave speculum, a little nearer than it's principal focus, the image of the picture will appear extremely natural, and very nearly like the real one from whence it was taken. For not only the objects are greatly magnified, so as to approach nearer their natural size; but they have also different apparent distances, insomuch, that a view of the inside of a church appears very like a real church; and landscape pictures as the real objects would do, seen from the spot where the view was taken.

This curious phenomenon will be in a great measure accounted for, by attending to this diagram, *fig. 3, pl. 6*. Where the curve pqr is the geometrical image of the strait object PQR , or that curve which contains the foci of all the pencils of light that diverge from PR , and whose axes pass through the center o of the speculum BAC , after their reflection by that speculum. Now it is proved by geometry, that the geometrical image of a circle facing the speculum, and whose center is at Q , and whose diameter is PR , will be a hollow figure, formed by the rotation of the curve pqr , round the axis Oq . If this hollow figure is supposed to be a real thing, whose inside surface is variously distinguished into parts by different colours, and a picture of it be drawn upon the circle PR , the point of sight being at O ; a spectator placed at o , would be affected much

in the same manner, by rays coming to him from the picture, after reflection by the speculum, as he would by rays coming to him directly from the hollow figure, the speculum and the picture being removed; for in this case, *the hollow figure, and the geometrical image of the picture upon the circle, are both coincident.*

Again, the geometrical image of a rectangular parallelogram A B, *fig. 4, pl. 6*, placed where P Q R is, *fig. 3*, will be also a hollow figure; but more like a pyramid with four sides, than to the figure described by the rotation of the curve p q r. In like manner a lesser parallelogram within the former will have the image of it's sides like those of the former, but at a greater distance; and so likewise the sides of the several parallelograms c d, e f, &c. will have their images in a series one behind the other, the middlemost being farthest of all; so that the geometrical image of the whole figure does somewhat resemble the frustrum of a hollow pyramid with four sides, and which, on account of the greater apparent distance of the smaller or middle parts, appears nearly like a hollow prism, a section of which is p s t r.

Now if p s, or r t, be the length, and s t, or p r, the breadth of the inside of a church, a perspective view of which, from O, is drawn upon the plane P R, the geometrical figure will not be very unlike the church itself. For the picture upon the plane P R, is a figure properly consisting of several parallelograms diminishing towards the middle, after the manner of those above described; and if the picture be not too large in proportion to the size of the speculum, the curvities arising from the form of the speculum, will not be very considerable. But as most of the pencils of light entering the eye, diverge from points that are at great distances, their different divergencies are not alone

sufficient for determining the true place of their foci: and the apparent image of a blank surface placed at P R, will not appear near so concave as the geometrical image.

Here, however, we must have recourse to some other cause, and we shall find many concurring ones. The contiguous parts of the picture of the floor, for instance, form a long series of visible images, contiguous likewise to one another. The images of the remoter parts appear also at the same time fainter and smaller, because the pictures of the remoter parts of the real floor diminish faster in proportion, than the apparent distances of the images of the pictures increase; so that from all these causes conspiring together, the eye receives much the same impression as if it looked at a real floor; in both cases, the appearance is much the same; a long extended surface, a little diminished in breadth, and that gradually, towards the farther end. In like manner the walls appear erect and extended on each side, and the roof above facing the pavement; and all gradually inclining, after the same manner as a large room appears to the naked sight when viewed from one end. Besides the above helps, the window-lights in the sides, the shades of upright objects thrown upon the pavement, &c. in the pictures, do also contribute their share; and all conspiring together, do sufficiently outweigh the imperfections of the geometrical image. So that instead of a distorted picture, we see in a manner a real church; the great magnitude of the whole, it's visible concavity, and proportionable length and distance of parts, all contributing powerfully to excite this idea. Landscapes, &c. are in like manner surprizingly improved by a concave speculum.

These phenomena appear rather more perfect to both eyes than to one alone; and the appearance

ance will be the same to one who does not know what the picture on the paper represents, which proves that the said phenomena are not founded upon mere prejudice. A young child, who had never seen any thing like what was represented, shews great marks of joy and surprize upon looking at a print in a concave speculum. If it can be said that nature is any where improved upon, I think this is the place: for if the print or picture be finely executed, the opportunity we have of viewing it's image without any extraneous light intruding into the eye, is an advantage we cannot have when we look at remote objects, and is productive of a wonderful effect.

OF VISION BY LIGHT REFLECTED AT A CONVEX SPECULUM.

We have very little to add to what we have already said on this subject. In a convex speculum, the images of objects are always seen erect, a little convexed towards the eye, and diminished, yet pretty nigh to the speculum; and the greater the convexity, the nearer, the smaller, and the more convex will the images of objects be.

If the speculum be a pretty large segment, it will exhibit the images of the objects that are pretty wide asunder; so that part of the cieling, floor, and two sides of the room, may be seen at the same time, the whole making a kind of picture very agreeable in it's effect: and the nearer the eye is to the speculum, the larger will be the field of the visible images. *The appearance is a kind of mean between the objects themselves and a good picture of them on a flat surface; and upon this account, and also for grouping the objects, a convex speculum may be very useful to a landscape painter.*

If, while the objects and speculum remain fixed,

fixed, you move to or from the speculum, the apparent places and magnitudes of the images will remain invariable: but if an object moves to or from the speculum, its images will also appear to move the contrary way; and as it approaches nearer or recedes farther, it will appear more and more enlarged or diminished.

If a convex mirror be placed against a window having an extensive prospect, or facing the end of a street, the great multiplicity of objects that are seen one behind the other, and the diminution of their images, will sometimes, after poring into the speculum, make us fancy they are a great way off; and, perhaps, further than the objects themselves. But on looking more attentively, this mistake will be corrected, and the apparent places of the images will not differ sensibly from their real places, or those places whence the rays diverge to the eye.

OF VISION BY PLANE SPECULUMS.

We have already explained to you the abstract theory of images formed by the reflection and refraction of plane and spherical mirrors; I shall now consider the phenomena of vision by plane mirrors.

Objects, as we have observed, seen by reflection of plane speculums, generally appear so perfect and natural, that if the speculum itself is not perceived, we are liable to mistake the images for the real objects of which they are the types. A man appears alive, corporeal, and not a mere surface; and any series of objects placed before the speculum exhibit alike series on the other side, all appearing in their due places, agreeable to the theory of images and of vision; with this difference, that the images appear somewhat darker than the objects, on account of the loss of light by reflection; and this, when the images are remote, will

will affect their apparent distances; and more especially if, as the case often is, part of the floor sustaining the real objects is not seen, or if the speculum is not vertical. But when the images are near, these causes have no sensible effect.

When you see your own image, or that of an object behind you, in the speculum, if the image be erect, it will appear inverted as to right and left; and the reason is, because the object and the image face each other, or look contrariwise. The case is not unlike, when the object is between us and the speculum, though we are apt to make it different for want of considering that it is the back of that towards us, and so call that the right side of the object, which we should call the left, if we were on the other side. The phenomena of vision in plane speculums agree so well with the theory of images, that we need say nothing more on this head, but proceed to explain the phenomena, when two or more speculums are combined together, or when one is placed in an inclined situation.

If a plane mirror be inclined to the horizon in an angle of 45 degrees, with it's face downwards, an upright object will have it's image in an horizontal position, and the image of an object lying horizontal will be erect.

If AB, fig. 6, pl. 6, be a plane looking-glass, with it's reflecting surface downwards, and CD be an object parallel to the horizon, then the mirror AB, which makes half a right angle will make half a right angle with the object; or ABC will be an angle of 45° . Now, at whatever distance a point C, in the object is from the mirror, the correspondent c, in the image will appear at the same distance from the mirror on the other side; therefore CE will be equal to cE: for the same reason any other point D, will be just as far distant before the mirror as it's correspondent point

point d is behind it; so that as the object forms an angle of 45° on one side of the mirror, the image will form also an angle (from the same angular point) of 45° on the other, 45 added to 45 making 90° , or a right angle, so that the image is perpendicular to the object, and being therefore perpendicular to the horizon will appear erect. For the same reason, an upright object will have it's image in an horizontal position; consequently if you stand upright before a mirror inclined to the horizon, the face upwards, you will see your image extended horizontally, as it were, on the floor, with your face upwards.

Hence, if you look into a plane speculum, inclined to the horizon in an angle of 45° , but with the face downwards, you will see yourself as it were in a flying posture; you will seem to be suspended horizontally in the air with your face downwards; and if the speculum is sufficiently long, you will seem to fly upwards or downwards, as you walk to or from the speculum.

If the speculum be inclined in any other angle, the angle of the image will be varied in the same manner: these positions you may easily verify by means of a common dressing-glass, as the inclination thereof may be altered at pleasure.

On these principles is constructed an optical deception, which Dr. Hooper has named the *animated optic balls*. On a flat board a serpentine groove is formed in such manner, that if the board be inclined, and a small ivory ball be placed at the top of the uppermost groove, it will roll with the same velocity till it gets to the bottom. This board is placed in a box in which there is a looking-glass so inclined that the board appears vertical, and the lower end uppermost; consequently the ball will seem to roll upwards. When this experiment is made to be exhibited in public,

every

every thing is contrived to conceal the principle, and heighten the deception.

In any number of plane speculums, all lying in the same plane, there can be seen, from the same place, only one image of the same object. For let there be ever so many, they have only the effect of one mirror, and the object is seen by rays proceeding therefrom to the eye.

If an eye is at I, fig. 7, pl. 6, within the angle ABC, formed by two plane mirrors AB, BC, it will see as many images of an object O, placed also within this angle, as you can let fall perpendiculars successively on the mirror from the object and each of the images.

1. Let fall the perpendicular OD, on the mirror BC; make ND equal to NO, and the point D will be the place of the image: for if you draw ID from the eye, and from g, where it meets the mirror, draw go, you will find the angle of incidence OgN equal to the angle BgI.

2. If from the point D you let fall on the mirror AB, the perpendicular DE, and make kE = kD, the point E will, for the same reasons, be the place of the second image, whose object is D.

3. If from E you let fall on the mirror BC, a perpendicular EQ, and make QF equal to EQ, F will be the place of the third image, of which E is the object.

4. If from F a perpendicular is let fall on AB, it will pass beyond B to FG, beyond the limits of the mirrors.

In the same manner you may shew that there is in H, an image of the object O, seen by the ray lh, reflected by the incident ray Oh; and a second in K, seen by the ray cl, reflected from ct, reflected

reflected from the incident ray Ot , that there is a third in L , seen by the incident ray OI , reflected in la , and then in $a k$, and afterwards in $k I$; and that there can be no more, because the perpendicular LM , from the last image, falls without the mirror.

From the figure you will see, that the first image is seen by one reflected ray; the second by two; the third by three; and so on.

The distance of each image from the eye is equal to it's incident ray, added to the sum of it's reflected ray.

The first image is brighter than the second, the second than the third; and so of the rest: for the intensity of the light is continually diminished, a considerable quantity being lost at every reflection.

The larger the angle formed by the mirrors, the fewer the number of images; for the cathetus of incidence, separate from each other by an angular motion, equal to that with which the mirrors are separated, and are consequently carried nearer and nearer to the angular, and fall successively beyond it; so that when the mirrors form a right angle, there can be but two images, and when it is very obtuse, there can be but one; the number of perpendiculars that can be let fall from the object or the images of the object on the two mirrors.

If the two mirrors are parallel, and infinitely extended, there would be an infinite number of images; but, as they go on, their distance is greater, and their brightness less; they therefore soon become insensible. So that if two plane mirrors be placed parallel to each other, there will be a series of images of the floor or space between them, indefinitely extended both ways; there being no other limitation of their number than what is caused by the decrease of light from the continued
reflec-

reflections. If you stand between two such mirrors, you will see in that fronting you, the images both of your fore and back part repeated several times, but continually fainter the farther off.

On this principle are constructed a variety of ingenious recreations; particularly those that are termed *the boundless gallery*, *the magical mirrors*.

The first of these consists of a long box, furnished at each end with a mirror, placed directly opposite to each other; a small quantity of quicksilver is taken off from one of them, in order that you may view these in the inside of the box; two or three painted scenes are placed in the box, and the top is covered with gauze. The scenes being painted on both sides, are successively reflected from one mirror to the other: if, for example, the painting consists of trees, they will appear like a very long vista, of which the eye cannot discern the end; for each mirror repeating the objects continually more faintly, contribute greatly to augment the illusion.

The other consists of a square box, with four plane mirrors placed perpendicular to the bottom of the box, certain objects in relief are placed on the bottom, and the top covered with gauze placed sloping-wise like the roof of an house, leaving only an aperture at the top for the eye. When you look in the box, you will find that the mirrors, from being opposed to each other, mutually reflect the inclosed figures; the eye beholds a boundless extent completely covered with these objects, and if they are properly disposed, the illusion will occasion no small surprise, and afford great entertainment.

In a single plane mirror, that is made of thick glass with quicksilver behind it, many images of any bright object, as a candle, may be seen.

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The first surface of the glass being solid and polished, is itself a mirror, which sends back all the rays which do not traverse the glass, and thus forms a weak image of the object. By looking at a candle obliquely in a mirror, you will see very evidently, by it's exhibiting a series of images, that the rays of light are reflected several times between it's surfaces: the images, however, all decrease in brightness, till at last the rays become too faint to exhibit an image. These are more distinguishable, the more obliquely they are viewed. This phenomenon proves very plainly, that light suffers a considerable diminution in it's passage through glass.

If a plane mirror turns upon an axis, the angular motion of the images is double that of the mirror.

Let AB , fig. 2, pl. 6, be a mirror, OE an incident ray, EF a reflected ray. Now suppose the mirror to turn upon an axis at E , and to take the situation CD , then the incident OE will have GE for it's reflected ray. Now the angle $FE G$, which expresses the angular motion or quantity, that the reflected ray has moved from it's first situation FE , is double of AEC , the angular motion of the mirror. If, therefore, the mirror moves one quarter of a circle, the reflected ray moves a half circle: it is for this reason that the images of the sun, by a mirror, move so fast; and hence, also, the images thereof reflected by water, even nearly quiet, appear much agitated, particularly when received at some distance from the point of incidence.

To judge of the goodness of plane mirrors. Having endeavoured to explain the principle of the phenomena of plane mirrors, I shall now proceed to such observations as may enable you to judge of their goodness. A speculum should be

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exactly figured and well polished. The goodness of the figure of a plane speculum is easily known, by observing if images seen in all positions, especially in very oblique ones, and from all parts of the speculum, appear exactly equal, and similar to the objects: that is, if the images, especially the remotest objects in the room, appear natural, without having any part of them distorted, the speculum has a good figure. The strait edges of the rails of wainscot are good objects for the experiment. A plane must be exceedingly erroneous, that will distort a face looking into it, because the rays being returned almost directly back to the eye, small aberrations cannot be sensible. But if two persons look at each other's image as obliquely as they can, they will soon perceive if the speculum be faulty.

It is deemed a very difficult thing to grind a *true plane*; and the difficulty of making a good looking-glass is still greater, because the two sides should be exactly parallel as well as flat. If the images of a candle seen very obliquely, and in different obliquities, and from all parts of the glass, do not always keep pretty nearly at equal distances one from another; it is a proof that the sides of the glass are neither flat nor parallel.

The better a speculum is polished, the brighter will be the images; that is, the eye will receive more light from it. The darker the colour of a glass speculum, the higher is the polish. Different glasses, though equally well polished, will not always appear equally dark; yet generally the above rule takes place, and the darkest is to be preferred.

LECTURE

LECTURE XVII.

ON THE NATURE OF VISION.

IT has been my endeavour, in the preceding Lectures, to rescue Philosophy from the imputation she has long lain under of being dangerous to religion and piety. It was not uncommon formerly to suspect every one who professed to pursue the light of nature, of unsoundness of principles, and of a secret design to undermine the belief of a Providence, and the being of a God. Nor can it be denied, that there has been ground for such a suspicion; for those who really had such evil designs, proceeded by attempting to explain the surrounding phenomena by the powers of nature, and thus endeavouring to confine the attention of mankind to them alone. But the state of natural philosophy is now altered; it is become an innocent, inoffensive science, a useful minister in the temple of the LORD.

In ancient times, nature was esteemed an original source of being, distinct from the ALMIGHTY; matter was thought to be possessed of a being which HE never gave it, and the elements to have their differences and qualities independent of *him*. These notions have long since been exploded, and God is acknowledged to be the *creator* of all things visible and invisible. It is now clear, that the abstract and sensible essences of nature receive their permanency, and her courses their stability, from the covenant or immutable will of God; her substances, both material and spiritual, together with their primary as well as secondary qualities, their applications to one another; their mutual affections, and all effects and events resulting therefrom, being derived primarily from no other source than the *power*, the *wisdom*,
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and

and the *goodness* of God. Nature is the work of God, her acts are his acts, her productions his gifts, her every operation an execution of his will. "Great, then, is the error of those who have set up *nature* as a first principle, in the place of God, whereby to account for physical operations and productions; for nature is nothing in itself, but a mere word without any meaning or idea belonging to it, if considered in any other view than as that system of laws whereby God upholds this visible world, and produces the infinite variety of forms and effects in it, according to an established and regular course of subordinate causes and means; and consequently, where the mind terminates it's views in a supposed nature as a self-moving agent or principle, it robs God of the honour due to his majesty, and transfers it to an *idol* of it's own making."

The study of the human frame, &c. has been regarded with the same unfavourable suspicion as philosophy. For there being a great deal of mechanism in the human composition, those who applied to a close examination and study of the machine, were apt to think too slightly of the spiritual part, insomuch, that it has been a current saying, wherever you see three physicians, you see two atheists. But I do not apprehend that they now retain the same sentiments. They erred, because they saw that the understanding might sometimes be restored to madmen by medicines: they knew that some of their drugs had a powerful effect upon the imagination, so as to warm it with sanguine hope, or chill it with desponding melancholy: they found that a delicacy of texture in the fibres of the brain, a purity of the circulating juices, had an influence on the natural talents, and occasioned a predominancy of some one of the principal humours that distinguished the characters of men; that

that an unnatural preffure, or a little heterogeneous mixture in the medullary substance within the head, disabled the soul from exercising her functions; and that in general the tenour and colour of our thoughts depended very much upon the disposition of the body. Arguing from *appearances*, which will ever mislead, they imagined that powers had been ascribed to the soul, which really resided in the body, and were tempted in an evil hour too hastily to conclude, that she had none belonging to her; but that thought itself, with all it's varieties, were nothing more than mere configuration and a diversity of motions in matter.

“ Beginning at the wrong end, and tracing the intellectual operations from organized matter as their source and cause; they could not but infer, that the cause being taken away, the effect must necessarily cease. Seeing that a contusion, or other injury of the brain, occasions a disorder or loss of the understanding and memory, they thence argued that the brain is the principal cause or foundation of these powers; whereas perception, thought, and memory, do not flow from the brain, but from the *mind* into it, as the proper medium for the manifestation of the intellectual powers. The defect or destruction of the organ does not occasion any absolute loss or annihilation of intellect, for that still remains the same in it's own spiritual principle, it only hinders it from manifesting it's operations in the natural world.” To suppose that *mind* and *matter* are the same, because the disorder of the body apparently influences the soul, is as absurd as to say that the *art*, *science*, and *intelligence* of a musician, lies entirely in the strings or pipes of his instrument, because his knowledge is more or less conspicuous, according as they are more or less tuned. It is a sophistry that can only dazzle superficial

ficial minds, that thus take appearances for realities, effects for causes.

But this temptation is now removed; for a more exact scrutiny into the properties of matter has clearly shewn, that no assortment of matter, how nicely soever arranged, can form an intelligent being. Let materialists insist as strongly as they please, that the characters and thoughts of men result from their machinery and organization; we know that no such result could take place, unless there were a *perceptive spirit* to receive the action of the machine. To imagine otherwise would be as absurd as to suppose that a bible might teach a sentiment of religion without a reader to peruse it, or the grass a sensation of green, without an eye to discern it. Some things, indeed, the *mind* performs through the *body*; as for example, the various works and energies of art. Others it performs without such a medium, as when it thinks, and reasons, and concludes. Now, though the mind, in either case, may be called the principal source, yet these last are most properly it's own peculiar acts, as more immediately referable to it's peculiar powers; and thus is mind ultimately the cause of all.

“The ancient *atheists*, as Anaximander, Democritus, &c. founded their tenets on the hypothesis of matter being the first and only principle, to the exclusion of all spiritual substances. Their followers in infidelity, in modern times, have done the same: nor, indeed, is there any other supposition, weak as it is, on which the system of atheism can be raised.”

“That the absurdities of a doctrine, which banished all wise designs and final causes from the creation and government of the world, might not, by unsupported assertions, shock the common sense of mankind, the authors and abettors of

this

this impious scheme employed their invention to form theories to account for effects without causes, or at least, without adequate causes; as by maintaining the eternity of the world in it's present form; or advancing, at least, an eternity of atoms, which, by the direction of chance, and a lucky jumble, formed themselves into the present orderly system."

"But as they were equally puzzled to account for life, consciousness, and intellect, upon their corpuscular plan, they found themselves under the necessity of ascribing to matter, under particular modifications, certain active powers, which are absolutely inconsistent with it's known essential properties, affirming the soul to be nothing more than a mere refined and delicate configuration of atoms, and the mental operations to proceed from the mechanical motions of rarified matter: thus making the principles of life and understanding to be only the modes of that which has nothing vital or intelligent in it, and thus *ascribing more to the effect than is in the cause to give*. These complicated absurdities have been so thoroughly detected and confuted, that atheism, as a system, scarce lifts up it's head, but hides itself under false colours. It does not now present itself as the open, but as the whited sepulchre; does not professedly declare war against the majesty and existence of Almighty God, but silyly endeavours to undermine his attributes, and by false reasoning to invalidate the proofs of the immortality of the soul."

Some philosophers among the ancients, as well as among the moderns, imagined that man was nothing but mere matter; but matter so curiously organized, that the impression of external objects produces in it sensation, perception, remembrance, and all the other mental operations. This foolish opinion could have no other origin

than the constant connection the Author of nature hath established between certain impressions made upon our senses, and our perception of the objects by which the impression is made; from which they weakly inferred, that those impressions were the proper efficient causes of the corresponding perception.*

But no reasoning can be more fallacious than this; that because two things are always conjoined, one must be the cause of the other. Day and night have been joined in a constant succession since the beginning of the world: but who is so foolish as to conclude from this, that day is the cause of night, or night the cause of the following day? There is, indeed, nothing more ridiculous than to imagine, that any motion or modification of matter should produce thought, and render it capable of sensation and knowledge. For those things, which are inferior and secondary, can by no means be the principles or causes of the more excellent.

If any one should relate of a telescope, so exactly made as to have the power of seeing; of a whispering-gallery, that had the power of hearing; of a cabinet so nicely framed as to have the power of memory; or of a machine so delicate as to feel pain when it was touched; the relation would be so absurd, and so shocking to common sense, that it would not find belief even among savages. Yet it is the same absurdity to think, that the impressions of external objects upon the machine of our bodies, can be the real efficient cause of thought and perception. The most perfect organization is but a perfect arrangement of *material elements*, and gives but a new extrinsic relation of parts to parts, and *can never give capacities which did not before exist*. Nay, the very materialist

* See Reid on the Intellectual Powers of Man, p. 34.

rialist himself, with all his boasted attachment to matter, is forced to have recourse to *powers* which are as different from the common capacities of body, as *the sentient substance* of the immaterialist is from the material element. Even the *man of matter*, when speaking of *resistance* in bodies, says, "that RESISTANCE is in most cases caused by something of a quite different nature from any thing MATERIAL."*

It is no wonder that philosophers, whose ideas of *mind* and *being* are only derived from *body* and *sensation*, should be thus inconsistent; for they have a short method of explaining away the nature of *truth*. They reduce it to mere *opinion*, and consider it as a factitious thing which every man makes for himself; which comes and goes just as it is remembered or forgot; which, in the order of things, makes it's appearance the *last* of any, being not only subsequent to sensible objects, but even to our *sensations* of them.

But there are other reasoners, who have had different notions; who represent truth not as the *last*, but the *first* of beings; who call it immutable, eternal, omnipresent. To these it must appear somewhat strange, how men should imagine, that a crude account of the method *how they perceive truth*, was to pass for an account of *truth itself*: as if to describe the road to London, could be called a description of that metropolis.

You are better learned than to consider truth as opinion: you know that it shines with unchangeable splendor, enlightening throughout the universe every possible subject susceptible of it's benign influence. Passions, and other objects, may prevent indeed it's efficacy, as clouds and vapours may obscure the sun; but itself neither admits

* For a confutation of materialism, see Berrington's Letters on Materialism—Immaterialism Delineated—and Harris's Hermes.

admits *diminution* nor *change*, because the darkness only respects particular *percipients*. Among *these*, therefore, you must look for ignorance and error, and for that *subordination of intelligence* which is their natural consequence.

From all these considerations you will, I hope, be persuaded to flee from *materialism* as from the plague. It is an opinion that is inimical to virtue, that darkens the prospects of futurity, unbinds the reins to vice, and is destructive of all true religion.

Having given you an account of the general theory of reflection and refraction of light, I shall now proceed to the theory of vision. The subject is not only curious and entertaining in itself, but without it there is no accounting for several optical phenomena, or even understanding the theory of optical instruments, and the manner by which they extend so prodigiously the natural boundaries of vision. It is also presumed, that it can be no unpleasing speculation to obtain an idea of the secret mechanism by which the eye communicates so many diversified and animated perceptions to the soul, and by which we are enabled to discover, with so much ease and rapidity, every surrounding object.

In the structure of the eye you will find the most evident manifestations of exquisite art and design, every part elegantly framed, nicely adjusted, and commodiously placed, to answer in the most perfect manner every possible good purpose, and thus evince that it is the work of unerring *wisdom*, prompted to action by infinite *love*.

So manifold are the blessings we derive from this organ, that the mind of man seems almost inadequate to the conception, and his pen to the description of them. While it forms our ideas
of

of magnitude and distance, it annihilates space, by placing the nearest and most distant objects close together. To it we are indebted for the delightful sensations that arise from the proportion and variety of forms, the harmonious mixture of colours, and the graces of beauty. It enables us to seek, to see, and to chuse our food; to go here and there, as the calls of friendship, or the occasions of business, require; to traverse the ocean, ransack the bowels of the earth, visit distant regions, accumulate wealth, and multiply knowledge. Assisted by it, we become acquainted with the works of the CREATOR, and can trace his wisdom, his power, and his goodness, in the texture of plants, the mechanism of animals, and the glories of the heavens.

The value of this sense is heightened, when we consider the miseries attendant on the want of it; for among the numerous evils that afflict the human race, there is none more justly dreaded, nor more deeply deplored, than a deprivation of sight. It is to have one of the chief inlets of happiness cut off, to be shut up in perpetual darkness, to labour under ten thousand inconveniences, and to be exposed to continual dangers. How poignantly this loss was felt by our great poet, is painfully evident from his own words:

“ With the year
Seasons return; but not to me returns
Day, or the sweet approach of ev’n or morn,
Or sight of vernal bloom, or summer’s rose,
Or flocks, or herds, or human face divine;
But cloud instead, and ever-during dark
Surrounds me, from the chearful rays of men
Cut off, and for the book of knowledge fair,
Presented with an universal blank

Of

Of nature's works, to me expung'd and raz'd,
And wisdom at one entrance quite shut out."

A SHORT DESCRIPTION OF THE EYE.*

In describing the eye, it is natural to consider, first, the external parts; then the internal, or those which are more immediately subservient to the purposes of vision.

The eye, as is well known, is situated below the forehead; it is placed in a bony cavity, called the *orbit*; the form is globular, it is composed of several coats and humours, and furnished with vessels properly adapted to it's various functions.

The eye consists of several *coats* or teguments, which form a *ball* perfectly globular except on the fore part, which is a little more protuberant than the rest. Within this ball are included three different liquids or transparent substances, called humours.

The *orbit* of the eye is of a conical shape, but rather irregular in it's dimensions; it is composed of seven bones, and lined with fat, which forms a soft bed for the eye to rest on, and facilitates it's various motions. A considerable part of the bottom of the orbit is open for the admission and transmission of the nerves, veins, and arteries.

Those prominent arches of hair, which we term the *eyebrows*, defend the eyes from the light when it is too strong, and prevent their being incommoded by any substances that might slide down the forehead, and thence fall into the eyes. That the eyebrows may be more effectually useful, and form a more perfect screen, they are furnished with muscles to draw them down, and corrugate them;

* What follows on this subject is extracted from my "Essay on Vision."

them; and when we are walking in a dusty road, or when we are exposed to a dazzling light, we pull down the eyebrows, and thereby shade the eye from the glare, and protect it from the dust. We may gather from hence, that those shades which encompass the forehead, and that project about three inches from it, are properly adapted to guard weak eyes from every offensive glare of light.

The prominency of the eyebrows gives a character to the face; and hence Le Brun, in his directions to a painter, with regard to the passions, places in them the principal force of expression. The eyebrows form a deep shade on the canvas, which relieves the other colours and features. A depression of the eyebrow is an indication of concern and grief; whilst an elevation thereof shews that the mind is either affected with joy, or enjoying the serene delights of tranquillity.

The *eyelids*, like two substantial curtains, protect and cover the eyes while we sleep; when we are awake, they diffuse, by their motion, a fluid over the eye, which cleans and polishes it, and thus renders it fitter for transmitting the rays of light.

Each eye is furnished with two lids, the one superior, the other inferior, joining at the two extremities, which are called *canthi*, or angles. Both eyelids are lined with a membrane, which also infolds as much of the globe of the eye as is called the white, and it prevents any dust, or other extraneous particles, from getting behind the eye into the orbit.

That the eyelids may shut with greater exactness, and not fall into wrinkles when they are elevated or depressed, each edge is stiffened by a cartilaginous arch. The eyelashes, like two palisades of short hair, proceed from these cartilaginous edges, warning the eye of danger, protecting

testing it from straggling motes, and warding off the wandering fly. They also intercept many rays proceeding from objects that are above the axis of vision, and thereby render the images of other objects more distinct and lively: for, as in the camera obscura, the image is always brightest when no rays are allowed to enter, but those which form the picture. The eyelashes contribute their share in giving beauty to the face, to soften the outlines of the eyelids, and throw a mildness on the features.

Both the eyelids are moveable; but the upper one mostly so, the lower one moving but little, being rather obsequious to the motions of the adjacent parts, than moved by any particular forces of it's own. The hairs of the eyelashes grow only to a certain length, and never need cutting: the points of the superior one are bent upwards, those of the lower eyelash downwards. Thus whenever we can trace things to their final cause, we find them always marked with design, and can find no circumstance so minute, as to escape the attention of the Supreme Being.

From what has been said, we may perceive why the sight of those, whose eyelashes are black, is, in general, much stronger than those who have them fair or white; the black eyelashes are a better shade for the eye, and reflect no light from their inner side, to weaken and efface the picture on the retina. *Montaltus* gives an account of a young man, whose eyelashes and eyebrows were of an intense white, and his sight obscure during the day, but clear at night. This person was taken prisoner by the Moors, who dyed his eyelashes black, by which his sight was much strengthened: in course of time the dye was washed off, and his sight became weak again. Dr. Russell, in his natural history of Aleppo, says, that it is the

the custom among the Turkish women to black the inside of their eyelids, not only as an ornament, but as a means of strengthening the sight. When the eyelids are lost, a symptom which frequently follows a malignant small-pox, the sight is always considerably impaired.

By shutting the eyelids partially, we can exclude as much light as we please, and thus further defend the eyes from too strong a light, which every one's experience proves to be as injurious to them as more gross matter. Numerous are the melancholy instances on record, which confirm this truth: Xenophon relates, that many of his troops were blinded by the strong reflection from the snow over which they were obliged to march. Dionysius, the tyrant of Sicily, among other means which he used to gratify his revenge, and satiate the cruelty of his temper, was accustomed to bring forth his miserable captives from the deep recesses of the darkest dungeons, into white and well-lighted rooms, that he might blind them by the sudden transition from one extreme to the other. Actuated by principles equally cruel, the Carthaginians cut off the eyelids of Regulus, and then exposed him to the bright rays of the sun, by which he was very soon blinded.

These facts make it clear that a protuberant eye is not so well calculated for vision, as one that is deep sunk in the head: neither extreme is indeed desirable; yet undoubtedly, of the two, that which is deep set is preferable, as affording the clearest sight, and being least liable to injuries from external accidents.

Those animals which have hard crustaceous eyes, as the lobster, crab, &c. have no eyelids; whereas most brute animals have an additional one, called the *nictitating membrane*, which they draw
over

over their eyes like a curtain, to wipe off whatever incommodes them.

The velocity with which the eyelids move to and fro is so great, that it does not in the least impede the sight. This curious circumstance may be illustrated by the well-known phenomenon of a burning coal appearing like a ring of fire, when whirled round about with rapidity, in the circumference of a circle. Now it is highly probable, that the sensation of the coal, in the several places of the circle, remains on the mind until it returns again to the same place. If, therefore, our eyelids take no longer time to pass and repass upon our eyes, than what the coal of fire takes to go round, the impression made by any object on the eye will suffer no sensible interruption from this motion.

To prevent the eyelids adhering together, they are supplied with a row of sebaceous glandules, which discharge a soft liniment, that mixes with, and is washed off with the tears.

The *lacrimal gland* is placed in the upper and outer part of the orbit. It is designed to furnish at all times water enough to keep the outer surface of the eye moist, and thus give the cornea a greater degree of pellucidity. In order that this liquor may be rightly disposed of, we frequently close the eyelids without being conscious of it.

At the inner corner of the eye, between the eyelids, stands a caruncle, whose office seems to be to keep that corner of the eye from being totally closed; so that any tears, &c. may flow from under the eyelids, when we sleep, into the *puncta lacrymalia*, which are little holes, one in each eyelid, near the corner, for carrying into the nose any superfluous tears.

The eye is furnished with six muscles, which spread their tendons far over the eye; by these it can

can be moved upwards and downwards to either side, and in every intermediate direction, and thus view surrounding objects without moving the head. To facilitate these motions, a great quantity of loose fat is placed all round the globe of the eye, between it and the orbit. Four of the muscles are strait, and two oblique; of the two strait muscles, two are situated vertically opposite one another, and the other two horizontally. Each of the six has a proper name, according to it's situation and office. I cannot pass over the muscles, without taking notice of a striking instance of design in the wise disposition of the parts. It is sometimes necessary to have an oblique motion of the eye, towards the nose, and there being no room on that side for muscles, a small bone is placed on the side of the nose, with a hole in it, to serve as a pulley, through which the tendon of a muscle passes to a convenient insertion, and thereby such an oblique motion is given to the eye, as would otherwise have been impossible.

The eyes are placed in the most eminent part of the body, near the brain, the seat of sensation. From their elevated situation, our prospect is enlarged, and the number of objects taken in at one view, increased; we command an ample horizon on earth, and a glorious hemisphere of the heavens.

Every part of the human frame affords indisputable proofs of the wisdom and beneficence of it's Creator, because all are adapted to answer in the best manner the end for which they were formed. Thus the globular figure of the eye is the most commodious we can form any idea of, the best adapted for facilitating the various motions of the eye, for containing the humours within, and receiving the images from without.

Many are the advantages that are derived from our having two eyes, some that are known, others

that are unknown ; for the correspondence of the double parts in the human frame, and their relation to the two great faculties of the human mind, has not been sufficiently attended to by anatomists. By having two eyes, the sight is rendered stronger, and the vision more perfect ; for as each eye looks upon the same object, a more forcible impression is made, and a livelier conception formed by the mind.

The eyes together view an object in a different situation from what either of them apart would do, and enable us to perceive small distances accurately. Hence we find, that those who have lost the sight of one eye, are apt to make mistakes in the distances of objects, even within arm's length, that are easily avoided by those who see with both eyes. Such mistakes are principally seen in snuffing a candle, threading a needle, or in filling a tea-cup. This aptness to misjudge distances and situations is, however, gradually diminished by time and practice.

When an object is placed at a moderate distance, we see more of it by means of the two eyes, than we possibly could with one ; the right eye seeing more of the right side, and the left eye more of it's corresponding side. Thus by both eyes we see in some measure round an object : and it is this which assists in giving that bold relieve, which we see in nature, and which no painting, how exquisite soever, can attain to. The painter must be contented with shading on a flat surface ; but the eyes, in observing natural objects, perceive not only the shading, but a part of the figure that lies behind those very shadings. The perception we have of distance with one eye, as was just now observed, is more uncertain, and more liable to deception, than that which we have by both ; therefore, if the shading and relief be executed in the best manner, the picture may have almost the same appearance to
one

one eye as the objects themselves would have, but it cannot have the same appearance to both. This is not the fault of the artist, but an imperfection in the art. To remove these defects, the connoisseurs in painting look at a picture with one eye through a tube, which excludes the view of all other objects. If the aperture in the tube next the eye be small, we have no means left to judge of the distance but the light and colour, which are in the painter's power.*

An object seen with both eyes, appears a little brighter, or more luminous, than it does when seen with one alone, as will be evident by looking alternately with both eyes and with one only: and the difference of brightness will be still more manifest, if at the same time that a part of a flat object, of an uniform colour, is seen with both eyes, the light from the adjacent part is excluded from one of them; which may be done, by applying a book to one side of the head, so that it may reach a little forwarder than the face. But although the difference of brightness, in the two cases, is very perceptible, yet it is not very considerable, nor is it easy to determine it accurately. Dr. Jurin, by a variety of experiments, concluded, that an object seen with both eyes, appeared only one thirteenth part brighter, than when seen with one alone.

Our eyes have an uniform or parallel motion, by which, when one is turned to the right or left, upwards or downwards, or strait forwards, the other always goes along with it in the same direction. When both eyes are open, we find them always turned the same way, as if both were acted upon by the same motive force. This phenomenon is the more singular, as the muscles which move the two eyes, and the nerves which serve the muscles, are entirely distinct and unconnected.

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* Reid's Inquiry into the Human Mind.

To account for and explain the cause of this motion, has puzzled the philosopher, and embarrassed the anatomist: that it originates from the grand moving principle, or generating cause within us, the mind, there can be little doubt; but how the mind operates, to produce this effect, we are altogether ignorant. Some effectual purposes are no doubt answered by this motion, for nothing is created in vain. One is supposed to be that of seeing objects single that are viewed with both eyes; for there are two pictures formed of every object, one in each eye. Hence, if any of the muscles of one eye, either from spasm, paralysis, or any other cause, is restrained from following the motion of the other, every object will be seen double. The same effect is produced, if, while we are looking at any object, we alter the direction of one of our eyes, by pressing it aside by the finger; an experiment frequently made by children, who are generally delighted with any uncommon appearance.

Whatever may be the cause, the fact is certain, that the object is not multiplied as well as the organ, and appears but one, though seen with two eyes: another instance of the skill of the contriver of this noble organ, and the exquisite art he employed in the formation of it.

Having considered the principal external parts of the eye, and shewn that they are framed to protect this delicate organ, with a care strictly proportioned to it's curious texture, and extensive usefulness, that it is fortified with strong bones, lodged in a deep receptacle, and guarded with a moveable cover; we now proceed to treat of the internal parts, or those which constitute the globe of the eye.

OF THE GLOBE OF THE EYE.

“ If the construction of the universe were not so evident a proof of the existence of a supremely wise and benevolent Creator, as to render particular arguments unnecessary, the structure of the eye might be offered as one, by no means the least; this instance, among numberless others, demonstrating that the best performances of art are infinitely short of those which are continually produced by the DIVINE MECHANIC.

The globe of the eye, or the organ of sight, may be defined in general as a kind of case consisting of several coats, containing three pellucid humours, which are so adjusted, that the rays proceeding from luminous objects, and admitted at a hole in the fore part of the eye, are brought to a focus on the back part of it, where they fall upon a soft pulpy substance, from whence the mind receives it's intelligence of visible objects.

It is not to be expected, that any account given of the eye can be altogether accurate; for as it is impossible to examine all the parts of the eye whilst in a natural and living state, so is it also nearly impossible, when it is taken out of it's socket, to preserve the figure of the parts entire; a circumstance, which accounts for the disagreement we find among anatomists.

OF THE COATS OF THE EYE.

The eye is composed externally of three coats or teguments, one covering the other, and forming a ball perfectly globular, except at the fore part, which is a little more protuberant than the rest; within this ball are three different substances, called humours.

The first, or outer coat, is called the *sclerotica*;
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the second, or middle one, is called the *choroides*, the interior one is named the *retina*.

Sclerotica. Cornea. The exterior membrane, which incloses and covers the whole eye, is called *sclerotica* and *cornea*: it is, however, strictly speaking, but one and the same membrane, with different names appropriated to different parts; the hinder and opake part being more generally denominated the *sclerotica*, the fore and transparent part the *cornea*.

The *sclerotica* is hard, elastic, of a white colour, resembling a kind of parchment; the hinder part is very thick and opake, but it grows gradually thinner as it advances towards the part where the white of the eye terminates. The fore part is thinner, and transparent; it is also more protuberant and convex than the rest of the eye, appearing like a segment of a small sphere applied to a larger, and is called *cornea* from it's transparency. The *cornea* is thick, strong, and insensible; it's transparency is necessary for the free admission of the light. This membrane is composed of several plates, laid one over the other, replenished with a clear water, and pellucid vessels; these plates are more evidently distinct in the fore than the hinder part. The *sclerotica* is embraced on it's outside by six muscles, by which the eye may be moved in any direction.

Choroides. Uvea. Iris. Under the *sclerotica* is a membrane, known by the name of the *choroides*; it is a soft and tender coat composed of innumerable vessels; it is concentric to the *sclerotica*, and adheres closely to it by a cellular substance, and many vessels. This membrane is outwardly of a brown colour, but inwardly of a more russet brown, almost black. Like the *sclerotica*, it is distinguished by two different names, the fore part being called the *uvea*, while the hinder part retains the name of the *choroides*.

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The fore part commences at the place where the cornea begins: it here attaches itself more strongly to the sclerotica by a cellular substance, forming a kind of white narrow circular rim: the choroides separates at this place from the sclerotica, changes it's direction, turning, or rather folding, directly inwards, towards the axis of the eye, cutting the eye as it were transversely: in the middle of this part is a round hole, called the pupil, or sight of the eye: the pupil is not exactly in the middle of the iris, that is to say, the centers of the pupil and iris do not coincide, the former being a little nearer the nose than the latter.

This part, when it has changed it's direction, is no longer called the choroides; but the anterior surface, which is of different colours, in different subjects, is called the *iris*; the posterior surface is called the *uvea*, from the black colour with which it is painted. The iris has a smooth velvet-like appearance, and seems to consist of small filaments regularly disposed, and directed towards the center of the pupil.

The eye is denominated blue, black, &c. according to the colour of the iris. The more general colours are the hazel and the blue, and very often both these colours are found in the same eye. It has been observed, that in general those, whose hair and complexion are light-coloured, have the iris blue or grey; and on the contrary, those whose hair and complexion are dark, have the iris of a deep brown: whether this occasions any difference in the sense of vision, is not discoverable. Those eyes which are called black, when narrowly inspected, are only of a dark hazel colour, appearing black, because they are contrasted with the white of the eye. "The black and the blue are the most beautiful colours, and give most fire and vivacity of expression to the eye. In black eyes there is

more force and impetuosity; but the blue excel in sweetness and delicacy."

The pupil of the eye has no determinate size, being greater or smaller, according to the quantity of light that falls upon the eye. When the light is strong, or the visual object too luminous, we contract the pupil, in order to intercept a part of the light, which would otherwise hurt or dazzle our eyes; but when the light is weak, we enlarge the pupil, that a greater quantity may enter the eye, and thus make a stronger impression upon it. This aperture dilates also for viewing distant objects, and becomes narrower for such as are near. The contraction of the pupil is a state of violence, effected by an exertion of the will: the dilatation is a remission of power, or rather an intermission of volition.* The latitude of contraction and dilatation of the pupil is very considerable; and it is very admirable, that while the pupil changes it's magnitude it preserves it's figure.

Anatomists are not agreed, whether the iris be composed of two sets of fibres, the orbicular and radial, or of either. Haller says, he could never discover the orbicular fibres, even with a microscope; the radial seem visible to the naked eye, and are sufficient to answer all the purposes required in the motion of the iris: when the pupil is contracted the radial fibres are strait, when it is dilated they are drawn into serpentine folds.

In children this aperture is more dilated than in grown persons. In elderly people it is still smaller than in adults, and has but little motion; hence

* Anatomists observe, that in animals of prey, both beasts and birds, the pupil is round as in man, which fits them to see every way; but in large animals which feed on grass, the pupil is oblong horizontally, for taking in a large circular space of ground: the pupil in animals of the cat kind, which climb trees, and want to look upwards and downwards, is oblong vertically,

hence it is, that those who begin to want spectacles, are obliged to hold the candle between the eye and the paper they read, that the strong light of the candle may force their rigid pupils into such a state of contraction, as will enable them to see distinctly. Those who are short-sighted, have the pupils of their eyes, in general, very large; whereas in those whose eyes are perfect, or long-sighted, they are smaller.

The whole of the choroides is opaque, by which means no light is allowed to enter into the eye, but what passes through the pupil. To render this opacity more perfect, and the chamber of the eye still darker, the posterior surface of this membrane is covered all over with a black mucus, called the pigmentum nigrum. This pigment is thinnest upon the concave side of the choroides, near the retina, and on the fore side of the iris; but is thickest on the exterior side of the choroides, and the inner side of the uvea.

The circular edge of the choroides, at that part where it folds inwards to form the uvea, seems to be of a different substance from the rest of the membrane, being much harder, more dense, and of a white colour; it has been called by some writers the ciliary circle, because the ligamentum ciliare (of which we shall soon speak) arises from it.

Retina. The third and last membrane of the eye is called the retina, because it is *spread* like a *net* over the bottom of the eye; others derive the name from the resemblance of the net which the gladiators called *retarii*, employed to entangle their antagonists. It is the thinnest and least solid of the three coats, a fine expansion of the medullary part of the optic nerve. The convex side of it lines the choroides, the concave side covers the surface of the vitreous humour, terminating where the choroides folds inwards. It

is an essential organ of vision; on it the images of objects are represented, and their picture formed. This membrane appears to be black in infants, not so black at the age of twenty, of a greyish colour about the thirtieth year, and in very old age almost white. The retina, however, is always transparent and colourless: any apparent changes, therefore, of it's colour must depend upon alterations of the *pigmentum*, which is seen through it.

Optic Nerve. Behind all the coats is situated the optic nerve, which passes out of the scull, through a small hole in the bottom of the orbit which contains the eye. It enters the orbit a little inflected, of a figure somewhat round, but compressed, and is inserted into the globe of the eye, not in the middle, but a little higher and nearer to the nose; an artery runs through the optic nerve, goes strait through the vitreous humour, and spreads itself on the membrane that covers the backside of the crystalline.

Monf. Mariotte has demonstrated, that our eyes are insensible at the place where the optic nerve enters; if, therefore, this nerve had been situated in the axis of the eye itself, then the middle part of every object would have been invisible, and where all things contribute to make us see best, we should not have seen at all; but it is wisely placed by the divine artist for this and other advantageous purposes, not in the middle, but, as we have already observed, a little higher and nearer to the nose,

OF THE HUMOURS OF THE EYE,

The coats of the eye, which invest and support each other, after the manner of an onion, or other bulbous root, include it's humours, by
which

which name are understood three substances, the one a solid, the second a soft body, and the third truly a liquor. These substances are of such forms and transparency, as not only to transmit readily the rays of light, but also to give them the position best adapted for the purposes of vision. They are clear like water, and do not tinge the object with any particular colour.

Aqueous Humour. The most fluid of the three humours is called the aqueous one, filling the great interstice between the cornea and the pupil, and also the small space extending from the uvea to the crystalline lens; it is thin and clear like water, though somewhat more spirituous and viscous; it's quantity is so considerable, that it swells out the fore part of the eye into a protuberance very favourable to vision. The uvea swims in this fluid. It covers the forepart of the crystalline; that part of this humour, which lies before the uvea, communicates with that which is behind, by the hole which forms the pupil of the eye. It is included in a membrane, so tender, that it cannot be made visible, nor preserved, without the most concentrated lixivial fluid.

It has not been clearly ascertained whence this humour is derived; but it's source must be plentiful; for if the coat containing it be so wounded that all the humour runs out, and the eye be kept closed for a season, the wound will heal, and the fluid be recruited.

The colour and consistence of this humour alters with age; it becomes thicker, cloudy, and less transparent, as we advance in years, which is one reason, among others, why many elderly people do not reap all that benefit from spectacles which they might naturally expect.

Crystalline. The second humour of the eye is the crystalline, which is as transparent as the purest

purest crystal; and though less in quantity than the aqueous humour, yet it is of equal weight, being of a more dense and solid nature; in consistency it is somewhat like a hard jelly, growing softer from the middle outwards. Its form is that of a double convex lens, of unequal convexities, the most convex part being received into an equal concavity in the vitreous humour.

The crystalline is contained in a kind of case, or capsule, the fore part of which is very thick and elastic, the hinder part is thinner and softer. This capsule is suspended in its place by a muscle called *ligamentum ciliare*, which, together with the crystalline, divides the globe of the eye into two unequal portions; the first and smaller one contains the aqueous humour, the hinder and larger part the vitreous humour. The crystalline has no visible communication with its capsule, for as soon as this is opened the humour within slips clean out.

The crystalline is placed so, that its axis corresponds with that of the pupil, and consequently it is not exactly in a vertical plane dividing the eye into two equal parts, but somewhat nearer the nose. It is formed of concentric plates or scales, succeeding each other, and these scales are formed of fibres elegantly figured, and wound up in a stupendous manner; these are connected by cellular fibres, so as to form a tender cellular texture. Between these scales is a pellucid liquor, which in old age becomes of a yellow colour. The innermost scales lie closer together, and form at last a sort of nucleus, harder than the rest of the lens. The crystalline has no visible communication with its capsule, so that when this is opened, it readily slips out: some say, that a small quantity of water is effused round it. Leeuwenhoeck has computed that there are near

two thousand laminæ, or scales, in one cryſtalline, and that each of theſe is made up of a ſingle fibre, or fine thread, running this way and that, in ſeveral courſes, and meeting in as many centers, and yet not interfering with, or croſſing each other.

The yellow colour, wherewith the cryſtalline is more and more tinged as we advance in years, muſt make all objects appear more and more tinged with that colour: nor does our being inſenſible of any change in the colour of objects, prove to us that their colour continues the ſame; for in order that we ſhould be ſenſible of this change, the tincture muſt not only be conſiderable, but it muſt happen on a ſudden, as will be more fully explained hereafter. In the cataract it is opaque; the ſeat of this diſorder is in the cryſtalline lens.

Vitreous Humour. The vitreous is the third humour of the eye; it receives it's name from it's appearance, which is like that of melted glaſs. It is neither ſo hard as the cryſtalline, nor ſo liquid as the aqueous humour; it fills the greateſt part of the eye, extending from the inſertion of the optic nerve to the cryſtalline humour. It ſupports the retina, and keeps it at a proper diſtance for receiving and forming diſtinct images of objects.

The vitreous humour is contained in a very thin pellucid membrane, and concave at it's fore part, to receive the cryſtalline; at this place it's membrane divides into two, the one covering the cavity in which the cryſtalline lies, the other paſſing above, and covering the fore part of the cryſtalline, thus forming a kind of ſheath for the cryſtalline. The fabric of the vitreous humour is cellular, the ſubſtance of it being divided by a very fine transparent membrane into cel-

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lules, or little membranous compartments, containing a very transparent liquor.

Ligamentum Ciliare. There is still one part to be described, which, though very delicate and small, is of great importance; it is called the ligamentum ciliare, because it is composed of small filaments, or fibres, not unlike the cilia, or eyelashes; these fibres arise from the inside of the choroides, all round the circular edge, where it joins the uvea; from whence they run upon the fore part of the vitreous humour, at that place where it divides to cover the crystalline; those fibres are at some distance from one another, but the interstices are filled up with a dark-coloured mucus, giving it the appearance of a black membrane.

OF THE FIGURE REPRESENTING THE EYE.

Figure 1, represents a section of the eye through the middle, by an horizontal plane passing through both eyes; the diameter of the figure is about twice the diameter of the human eye.

The outermost coat, which is called *sclerotica*, is represented by the space between the two exterior circles BFB; the more globular part, adjoining to the sclerotica at the points BB, represented by the space between the two circles at BAB, is the *cornea*.

The next coat under the sclerotica is a membrane of less firmness, represented by the two innermost circles of BFB, and called the *choroides*.

Adjoining to the choroides, at BB, is a flat membrane, called the uvea. aa is the pupil, being a small hole in the uvea, a little nearer the nose than the middle.

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V the *optic nerve*; the fibres of this nerve, after their entrance into the eye, spread themselves over the choroides, forming a thin membrane, called the retina, and is represented in the figure by the thick shade contiguous to the circle BFB.

EE is the *crystalline* humour; it is suspended by a muscle BbbB, called the *ligamentum ciliare*. This muscle arises behind the uvea at BB; where the sclerotica and cornea join together at bb, it enters the capsula, and thence spreads over a great part of it's anterior surface.

The *aqueous* humour occupies the space BABbCb.

The larger space BbDbBF contains the *vitreous* humour.

The foregoing description, I presume, will be found sufficient to give a general idea of the construction of this wonderful organ: for a fuller account I must refer you to the writers on anatomy. Enough has been exhibited to shew with what art and wisdom the eye has been constructed. "And he must be very ignorant of it's structure, or have a strange cast of understanding, who can seriously doubt, whether or not the rays of light and the eye were made for one another, with consummate wisdom, and perfect skill in optics."

"If we should suppose an order of beings endued with every human faculty but that of sight, how incredible would it appear to such beings, accustomed only to the slow information of touch, that, by the addition of an organ, consisting of a ball and socket of an inch diameter, they might be enabled, in an instant of time, without changing their place, to perceive the disposition of a whole army, the order of a battle, the figure of a magnificent palace, or all the variety of a beautiful landscape? If a man were, by feeling, to find out the
figure

figure of the Peak of Teneriffe, or even of St. Peter's church at Rome, it would be the work of a life-time.

"It would appear still more incredible to such beings as we have supposed, if they were informed of the discoveries which may be made by this little organ, in things far beyond the reach of any other sense. That, by means of it, we can find our way on the pathless ocean, traverse the globe of the earth, determine it's size and figure, measure the planetary orbs, and make discoveries in the sphere of the fixed stars.

"Would it not appear still more astonishing to these beings, if they should be further informed, that by means of this organ we can perceive the tempers and dispositions, the affections and passions, of our fellow-creatures, even when they want most to conceal them? that by this organ we can often perceive what is strait and crooked, in the mind as well as the body? that it participates of every mental emotion, the softest and most tender, as well as the most violent and tumultuous? that it exhibits these emotions with force, and infuses into the soul of the spectator the fire and the agitation of that mind in which they originate? To many mysterious things must a blind man give credit, if he will believe the relations of those that see! his faith must exceed that which the poor sceptic derides as impossible, or condemns as absurd.

"It is not, therefore, without reason, that the faculty of seeing is looked upon as more noble than the other senses, as having something in it superior to sensation, as the sense of the understanding, the language of intelligence. The evidence of reason is called *seeing*, not feeling, smelling, tasting; nay, we express the manner of the divine knowledge by *seeing*, as that kind of knowledge which is the most perfect in ourselves."*

Or

* Reid's Inquiry into the Human Mind.

OF VISION.

The representation of objects upon a sheet of paper, by means of a lens placed at a hole in a window-shutter, is exceedingly similar to what happens to our eyes when we view objects. For vision, so far as our eyes are concerned, consists in nothing but such a refraction of the rays of light by the transparent skins and humours of the eye as will form a distinct picture of the object on the retina. For the structure of the eye plainly indicates, that in order to attain distinct vision, it is necessary that a certain quantity of rays from every visible point of an object should be united at the bottom of the eye, and that the points of union of the rays of the different pencils should be as distinct and separate as possible.

The eye is admirably contrived for effecting these purposes : all the rays coming from any visible point of an object, that can enter the pupil, are united closely together upon the retina, and thereby make a much more powerful and stronger impression than a single ray alone could do ; to answer this purpose, the retina is placed at a proper distance behind the refracting surfaces, and each pencil of rays is refracted orderly into distinct focuses, that the whole object may be distinctly seen at the same instant.

These effects are owing to the refraction of the rays of light ; for if these rays were not so refracted, very few of them would strike upon the least sensible point of the visionary nerve, and the rays from different objects, or from different parts of the same objects, would strike at the same place at once, and thus create an indistinctness equal to blindness.

When the light is weak or strong, the pupil is
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accordingly enlarged or contracted, for the admission of more or fewer rays, that the impressions on the retina may be rendered suitable to the respective cases.

As the crystalline humour is densest in the middle, it is highly probable that it is not equally refractive. This difference in density of the constituent parts of the crystalline is admirably contrived for correcting the aberration from it's figure, as well as that of the cornea. The more remote rays of each pencil, by passing through a medium gradually diminishing in density from the middle towards the extremes, have their focuses gradually lengthened, which correct the aberrations of the figure, that so they may unite nearer together. The concave figure of the retina is somewhat serviceable for the same purpose.

It is by no means easy to determine with accuracy the measure of refraction of the different humours of the eye; from such experiments as could be made, it has been found that the refractive powers of the aqueous and vitreous humours are much the same with common water, and that of the crystalline a little greater.

The cornea and aqueous humour being supposed to have the same refractive powers, all three may be considered as one dense medium, whose refractive surface is the cornea; and the crystalline humour may be considered as a convex lens, placed in a given position, within the said medium. Whence the humours of the eye all together make a kind of compound lens, whose effect in refracting rays, having a given focus of incidence, is easily found by the laws of optics.

I have constructed three models to explain the action of the rays of light upon the eye. These models are represented at *fig. 8 and 9, pl. 3; fig. 10, pl. 4.* The rays of light are here formed of silk strings

strings of different colours; the globe of the eye is represented by a glass ball. *Fig. 8, pl. 3*, is the natural state of the eye. *Fig. 9, pl. 3*, represents the rays falling short of the retina for a short-sighted eye. *Fig. 10, pl. 4*, exhibits the action of the rays in a long-sighted eye. Let P Q R, *fig. 8, pl. 3*, be an object; then the pencils of light B P B, B Q B, B R B, from the points P Q R, are first refracted by the cornea, so as to belong to focuses behind the eye; then by the anterior surface of the crystalline humour, they are again refracted towards focuses nearer to the eye than before; and lastly, in going out of the crystalline into the vitreous humour, they are again refracted, so as to unite in the points p q r. In like manner, the pencils of rays coming to the cornea from every physical point of the object P Q R, are, by the different refracting surfaces of the eye, brought orderly to unite upon the retina, and there form, as it were, an image p q r of the object, but in an inverted position; the upper part of the object being painted upon the lower part of the retina, the right side of the object upon the left of the retina, and so of other parts. Thus the cavity of the eye is a kind of *camera obscura*, the cornea and crystalline making a sort of compound lens, whose aperture is limited by the breadth a a of the pupil. And that the parts of the eye are adapted to produce such an image, may be proved by experiment: for if the tunica sclerotica be taken away from the back of an eye newly taken out of the head of any animal, and this eye be placed in a hole made in the window-shutter of a dark room, so that the bottom of the eye be towards you, a beautiful, but inverted, picture of external objects will be exhibited, painted in the most lively colours.

If the humours of the eye, by age, or any other cause, shrink and decay, the cornea and crystalline

grow flatter than before; and the rays not being sufficiently bent, arrive at the retina before they are united in their focus, and meet in some place behind it, see *fig. 13, pl. 4*, and therefore form an imperfect picture at the bottom of the eye, and exhibit the object in a confused and indistinct manner. This defect, of which we shall treat more particularly hereafter, is remedied by spectacles with convex glasses, which, by increasing the refraction of the rays of light, cause them to converge more, and thus convene distinctly at the bottom of the eye.

On the other hand, if the cornea and crystalline be too convex, the rays unite before their arrival at the retina, see *fig. 9, pl. 3*; and the image thereon is of course indistinct. This defect, like the preceding one, may be remedied by the use of glasses, though of a contrary figure; for here they must be concave, instead of convex: a lens, of a proper concavity, placed before the eye, will make the rays diverge so much more than they do in their natural state, as will cause them to meet at the retina.

OF THE ARTIFICIAL EYE.

If the eye of an animal be taken out, and the skin and fat be carefully stripped off from the back part of it, till only the thin membrane, which is called the retina, remains to terminate it behind, and any object be placed before the front of the eye, the picture of that object will be seen figured as with a pencil on the retina. There are thousands of experiments which prove that this is the mechanical effect of vision; but none of them which render it so evident as this with the eye of an animal: an eye of an ox newly killed, shews it happily, and with very little trouble.

The optical effects of vision may be very pleasingly

singly and satisfactorily illustrated by the instrument which is called an *artificial eye*, and which has been lately considerably improved by Mr. Smith.

The artificial eye is so constructed as not only to shew the optical effects of vision, but to give also an accurate idea of it's conformation. It is one of the most perfect and satisfactory instruments in a philosophical apparatus.

The part representing the globe of the eye, and containing the humours, is fixed in a socket where it may be moved in any direction. This socket is fixed to a screen to shade the eye, that the picture formed on the back part may be more distinct: the hole in the front of the screen is shaped and coloured so as to exhibit nearly the form of our eye.

Take the eye in your hand, and turn it towards any bright object, at a moderate distance, and you will see a lively, beautiful, distinct, but inverted picture of the object before it, on the rough part of the glass representing the retina.

Unscrew the cover that confines the ball of the eye, and take it out that we may dissect it. The outermost coat represents the *sclerotica*, the more protuberant part is the *cornea*.

This being removed, you find a plano-convex lens, representing the *first* chamber of the *aqueous* humour; under this is a flat piece of tortoiseshell, to represent the *iris*, with a hole in the middle for the *pupil*; this being removed, you find a plano-concave lens, forming the *second* chamber of the *aqueous* humour. Now take off the second coat, or the *choroides*, and you will find a small lens, whose sides are of unequal convexities, to represent the *crystalline* humour; underneath this is a large glass of the shape EDE V, *fig. 10, pl. 3*, occupying the rest

of the globular space, and answering to the vitreous humour.

To represent the nature of vision in a long-sighted eye, I substitute a plano-convex lens for the first chamber of the aqueous humour, whose convexity is less than that we used before. Turn the eye, in this state, towards a bright object, and you find the image thereof is very imperfect on the retina; but on applying a proper spectacle glass before the eye, you obtain a perfect image.

By substituting a more convex lens for the first chamber of the aqueous humour, we have a short-sighted eye, and an imperfect picture on the retina: by placing a proper concave lens before the eye, the rays are rendered less convergent, and made to unite at the retina, and there form a distinct image of the objects as before.

OF THE INVERTED POSITION OF THE IMAGE.

If vision be owing to the picture on the retina, it may be asked, why the object appears in it's natural *upright position*? how, when nature draws the picture the wrong way, her errors are so readily corrected?

If it were as easy a task to give a satisfactory explanation of this abstruse question, as it is to start objections to every system hitherto suggested, to account for the operations of the mind on the body, and the body on the mind, it would have been explained long ago.*

The difficulty would be still greater, if it was the picture we saw, and not the object; but the picture *is not seen at all*, the eye can see no part of itself; the picture is the instrument, by means of which

* See, on this subject, Reid on the Mind, Porterfield on the Eye, Hartley on Man, Bonnet's *Essai Analytique sur l'Ame*, Berkeley on Vision, &c. &c.

which the object is perceived ; but it is not perceived itself ; the instrument neither perceives, compares, nor judges ; these are powers peculiar to that psycological unity which we call the *mind*.

It is absolutely necessary, in considering this subject, to distinguish between the organ of perception, and the *being* that perceives. A man cannot see the satellites of Jupiter, unless assisted by a telescope : does he therefore conclude from this, that it is the telescope that sees those satellites ? By no means ; the conclusion would be absurd : nor would it be less absurd to conclude, that it is the eye that sees : the eye is a natural organ of sight, but the natural organ sees as little as the artificial.

Our senses are instruments, so framed by the Author of our being, that they correspond with, or have a determined relation to, those qualities in objects which they are to manifest to us. It is thus with the eye ; it is an instrument most admirably contrived for manifesting visible objects to the mind ; for this purpose, it refracts the rays of light, and forms a picture upon the retina ; but it neither sees the object, nor the picture. The eye will refract the rays of light, and form the picture, after it is taken out of the head, but no vision ensues. Even, when it is in it's proper place, and perfectly sound, an obstruction in the optic nerve takes away vision, though the eye has performed all it's functions.

We know, indeed, how the eye forms a picture of visible objects on the retina ; but how this picture makes us see objects, we know not : and if experiment had not informed us that such a picture was necessary, we should have been entirely ignorant of it. The seat of sensation, wherever it is placed, does not appear to be passive in receiving images ; the images are the occasion of it's re-action, and directing a ray from itself towards every object it perceives ;

perceives; and this action and re-action are reciprocal. Hence we often see objects when the eye is turned from them, and often do not see the object on which the eye is turned, if the attention be otherwise engaged.

The pictures upon the retina are, however, a mean of vision; for such as the picture is, or such as the action of the rays of light is on the retina, such is the appearance of the object in colour and figure, distinctness or indistinctness, brightness or faintness; but as we are totally ignorant of the mechanism of the mind, or of the organization of the mental eye, we cannot say how this effect operates, and can only conclude, that the natural eye is an instrument of vision.

It appears very clear from Dr. Darwin's experiments, that the retina is often in an active state, and that upon the activity of this organ many of the phenomena of vision depend; an impression on the retina being first made by an active power, which produces a conformable change and reaction, that passes directly to the sensorium, occasioning, though in an unknown manner, the perception of objects.

On a subject, therefore, confessedly so obscure, and which is perhaps beyond the limits of human conception in its present state, every explanation must be imperfect, every illustration inadequate. Among the various attempts of human sagacity, to shew why an *inverted image* is the mean of exhibiting objects to the mind in an upright position, the following is perhaps one of the least imperfect.

Every point of an object is seen in the direction of a right line, passing from the picture of that point on the retina, through the center of the eye, to the object point; and, therefore, such points indicate to the mind the existence of the object point, and its true situation; and of course, that the object,

ject, whose picture is lowest on the retina, must be seen in the highest direction from the eye; and that object, whose picture is on the right of the retina, must be seen on the left: so that by a natural law of our constitution, we see objects erect by inverted images, and if the pictures had been erect on the retina, we should have seen the object inverted.*

But supposing the preceding illustration to be the true one, and quite satisfactory, many difficulties still remain, to perplex the philosopher, and embarrass the anatomist. There are parts of the eye which assist in perfecting the organ of vision, whose nature and functions are among the desiderata of science. We are ignorant of the office of the optic nerve, or in what manner it performs that office. That it has some part in the faculty of seeing, is evident; because in an amaurosis, which is said to be a disorder of the optic nerve, the pictures on the retina are clear and distinct, and yet there is no vision.

We know still less of the use and functions of the choroid membrane; it is necessary, however, to vision; for it is well known, that a picture upon that part of the retina where it is not covered with the choroid, namely, at the entrance of the optic nerve, produces no more vision than a picture upon the hand.† There are, therefore, other material organs, whose operations are necessary to seeing, even after the pictures upon the retina are formed; whenever we become acquainted with

* Reid on the Human Mind.

† This is not conclusive, for where there is no choroid, there is no retina, the optic nerve being not yet expanded into that membrane. If the choroid was taken away from behind the retina, there is reason to believe that vision would still take place.

with the use of these parts, more links of the chain will be brought into our view, and we shall better comprehend this wonderful instrument.

Having had occasion to mention that there is no vision produced by that part of the retina which is not covered by the choroid membrane, it will be proper to illustrate this circumstance more fully, and shew in what manner this fact has been ascertained, the discovery of which occasioned a long controversy concerning the proper seat of vision.

Experiment. Fix three black patches, A, B, C, upon a white wall, at the height of the eye, A being to the left, and C to the right: place yourself facing these patches, shut the right eye, and direct the left towards the patch C, you will then see both A and C, but the middle patch B will disappear. Or if the left eye be shut, and the right directed towards A, you will still see both A and C, but B will disappear. If the eye be directed towards B, both B and A will be seen, and not C; for which ever of the patches is directly opposite to the optic nerve vanishes. This experiment is rather difficult at first, but becomes easy by a little practice. In our usual intercourse with common objects, we are not sensible of this defect, because we turn the visual parts of the eye with so much rapidity upon the invisible part of the object, that the loss, without peculiar attention, is imperceptible; this loss, however, in one eye, is remedied by the use of both, as the part of the object that is not seen by one, will be distinctly perceived by the other. This defect of sight, though common to every human eye, was never known, until it was discovered by the sagacity of Mons. Mariotte in the last century.

OF THE EXTENT OR LIMITS OF VISION.

Having considered the general principles of vision, I shall now proceed to consider further the nature, properties, and extent of power of the eyes. As in a dark chamber, a very slender beam of light is visible; so in all cases when the surrounding medium is very dark, objects are seen by small quantities of light. Hence, when the medium round the eye is dark, a small quantity of light will suffice for vision, the eye being, by the exclusion of the adventitious light, rendered sensible to the most delicate impressions.

The extent, therefore, of our sight is increased or diminished, in proportion to the quantity of light that surrounds us, supposing the illumination of the object to remain the same. Hence it has been calculated, that if the same object, which during the day we see at the distance of 3436 times it's diameter, were equally illuminated during the night, it would be visible at 100 times greater distance.

Thus in a dark night the feeble light of a candle may be seen at a great distance; and the fixed stars, though they have no sensible diameter, are visible, and the darker the night, the more of them are seen. A certain quantity of light is, however, necessary, even in this case, for vision; for the impressions of light from the satellites of Jupiter and Saturn, are too feeble to be perceived without the assistance of a telescope.

At the approach of day, and as the twilight increases, the eye begins to be enlightened by the reflection of the atmosphere, the stars grow fainter, and in proportion as the light increases, gradually disappear, first those of the least, and at last those of the largest magnitude. As the day advances,
the

the moon herself loses of her lustre, till at length her light is overpowered, and she is no longer seen. In the same manner, small particles are seen floating in a beam of light let into a darkened room; but as soon as the room is enlightened, those particles disappear.

One of the reasons why we are often unable to distinguish distant objects, is the profusion of rays reflected from intermediate objects, which, by their brilliancy, prevent us from perceiving the fainter rays that proceed from those which are more distant; so that when the objects are very remote, their picture on the retina is easily obliterated, by the vigorous and lively impressions made by those that are nearer. But when the intermediate ones emit a feeble light, when compared to that which proceeds from the more remote ones, these will form a distinct picture on the retina, and become perfectly visible.

The extent of vision is not only limited by the light of the ambient medium, which enters the eye with the pencils of light that proceed from surrounding objects; but it is further impeded by the heterogeneous particles that are constantly floating in the air: these, by their opacity and reflective power, form a kind of veil, that obscures the vision of remote objects; and the more the medium is loaded with these particles, and the more remote the object is from the spectator, the more obscure and indistinct it will appear, and the limits of vision be more confined.

The exhalations which continually rise from the earth, augment this obscurity, and render the air less transparent, especially near the earth: the celestial bodies generally, therefore, appear more obscure when near the horizon, than when they are at a greater elevation; because, in the first case, they are seen through that part of the atmosphere

mosphere which is contiguous to the surface of the earth; but in the latter, through a part which is at a greater distance.

Every one knows, that objects at a given distance are more distinctly seen, and are visible at a greater distance in clear, than in foggy weather. Thus early in a clear morning, and when the air is free from vapours, and not much enlightened, a hill or a head-land is visible at a great distance; but as the day advances, the land becomes more obscure, till at length, by the great opacity of the intervening vapour, and the light reflected by it to the eye, the object becomes less and less perceptible, and at last totally disappears. Hills, and other high lands, are seen more distinctly in the morning, partly from this circumstance, that by their elevation they are more illuminated than the parts intervening between them and the spectator.

But the obscurity arising from the exhalations is not the least part of the inconvenience they occasion; the rising exhalations have a kind of undulating motion, like that of smoke or steam, so that objects seen through them appear to have a tremulous or dancing motion, which is sensible even to the naked eye. If distant objects be viewed on a hot summer's day, this effect is so sensible in telescopes, as to render them entirely useless for terrestrial objects, when they augment apparent magnitude more than eighty times.

From this want of transparency in the atmosphere, arises that gradual diminution in the light of objects, which painters call the aerial perspective, by which they endeavour to give that degradation of colour, and indistinctness of outlines, peculiar to objects at a distance: for if the air were perfectly transparent, an object would

would be equally luminous at all distances, because the visible area and the density of light decrease in the same proportion.

Another cause which limits the extent of vision, and for the removal of which optical instruments are more particularly adapted, is their smallness in proportion to their distances: for excepting in the case of luminous objects seen in the dark, it is necessary that an image on the retina should have some determinate magnitude, in order to become perceptible; thus a house may be seen at a considerable distance, but we must approach nearer before the windows are discernible, and nearer still to distinguish the bricks.

It is not easy to determine with accuracy the quantity of the *minimum visibile*, or the angle that is subtended by the smallest visible object. Mr. Harris has inferred, from several experiments, that objects are seldom visible under an angle less than 40 seconds, and at a medium not less than two minutes.

A simple object, as a white or black square, upon the opposite colour, is perceivable under a less angle than the parts of a compound one. The more objects differ in colour, the more easily we can distinguish their several impressions on the retina: different degrees of light on the same object will render it visible at different distances, and under different angles: indeed the most general cause of the non-visibility of objects, is the want of sufficient light in the pencils that proceed from them; several contiguous objects are scarce discernible one from the other, unless they each subtend angles that are not less than four minutes.

A long slender object is visible under a smaller angle than a square object of the same breadth: a slender object, as a line, may be considered as consisting

sisting of several squares joined together; and though one of these squares may be too small to be seen, yet the pencils of light coming from each of them being contiguous, and striking at the same time upon the retina, are capable, by their united strength, to awaken the visive faculty, and so to render the objects visible from whence they came. For the same reason, a *small object in motion* is easier discerned than if at rest, and may be visible in the one case, though not in the other. A small star, by day or twilight, that cannot be easily seen through a telescope directed to it, will become visible by shaking or moving the telescope.

There is a great difference in the degree of sensibility of different eyes. We have been told of persons seeing a satellite of Jupiter without the assistance of glasses: a circumstance that to many appears incredible. But when we consider how much the various circumstances of light affect vision, and how much further our sight is extended at some favourable opportunities than at others, these extraordinary accounts may be the more readily credited.

The following calculation of M. de la Hire will give some idea of the extreme sensibility of the optic nerves. The sail of a windmill, six feet in diameter, may be easily seen at the distance of 4000 toises, and the eye being supposed to be an inch in diameter, the picture of this sail at the bottom of the eye will be the eight thousandth part of an inch. This shews with what wonderful accuracy the rays of light are refracted by the eye, so that a pencil of rays coming from one point of the object, shall meet in a point on the retina, so as not to deviate the eight thousandth part of an inch.

If an object be held too close to the eye, it becomes indistinct, and the more so the closer it is held, notwithstanding it's apparent magnitude is thereby increased, and a very slender object will become totally invisible.

To the generality of eyes, the nearest distance of distinct vision is about seven or eight inches; at this distance they commonly read a small print, and examine all minute objects. It is true some eyes can see small objects best at the distance of six, four, and even three inches; and some again at twelve, fifteen, or twenty inches; but these are only particular cases, and do not, therefore, affect the present inquiry.

A globular object that is less than $\frac{1}{16}$ inch in diameter, is, to the generality of eyes, totally invisible: and, excepting in few cases, an object cannot be seen that is less than $\frac{1}{16}$ inch in diameter; an object of that breadth subtending an angle of 1 *min.* at the distance of 8 inches from the eye. But when the field, on which the object is placed, is nearly of the same colour with it, we cannot see it under an angle less than about 4 *min.* In such circumstances the smallest visible object is not less than $\frac{1}{16}$ of an inch in diameter. At a medium, the size $\frac{1}{16}$ inch diameter is the size of the least globular object discernible by the naked eye.

OF DISTINCT AND INDISTINCT VISION.

It will be proper in this place to explain, with more accuracy, what is meant by distinct vision, and what is the difference between seeing an object distinctly, and seeing it clearly; as the clearness or brightness with which an object is seen, is often confounded with distinct vision.

We see an object *clearly*, when it is sufficiently illuminated, to enable us to form a general idea of

of it's figure, and distinguish it from other objects: we see it *distinctly*, when the outlines of it are well defined, when we can distinguish the parts of it, and determine their colour and situation. Thus we may be said to see a distant object *clearly*, when we can perceive that it is a tower; but to see it *distinctly*, we approach so near as to be able to determine not only it's general outline, but to distinguish the parts of which it is composed.

This may be made more evident, by advert-
ing to the experiment of the dark chamber, in
which we shall find a considerable difference be-
tween the distinctness and brightness of the picture;
and learn, that a confusion of the parts is not the
same thing with obscurity.

For the picture may be distinct in all it's
parts; the rays which come from one and the same
point in the object, may be exactly collected into
one and the same point upon the paper; and yet,
if but few rays pass through the lens, and conse-
quently the space where the picture is painted
should be but faintly enlightened, this picture,
though it is distinct, will be faint and obscure.
On the other hand, though the picture be con-
fused, either because the paper is placed at an
improper distance from the lens, or for any other
cause; yet if many rays pass through the lens, and
strongly illuminate the paper, the picture, not-
withstanding the want of distinctness, will be a
bright one.

*The brightness or clearness with which an object
is seen,* depends principally on the following cir-
cumstances.

1. On the quantity of light proceeding from
the object to the eye; and this is in a great mea-
sure regulated by the distance, for the intensity of

light diminishes in an inverse ratio to the square of the distances.

2. It depends on the colour of the object itself, and of those objects which surround it.

3. On the manner in which the light falls upon the object, and is reflected from it.

4. On the aperture of the pupil, for the wider this is, the greater will be the number of rays that are transmitted to the retina.

5. On the transparency and purity of the humours of the eye, and the soundness of the rest of the visive parts.

6. On the transparency of the atmosphere.

When all these circumstances concur, an object will appear bright and clear; but less so, in proportion as any of them are wanting. In order, however, to obtain distinct vision, it is requisite, not only that the object be sufficiently illuminated, but also that the several pencils, on their arrival at the retina, should be separate, and not mixed together; and when this is not the case, the outlines of the object and its parts will appear faint, hazy, and ill-defined. We may, therefore, consider the *following conditions as necessary towards obtaining distinct vision.*

1. The objects should be sufficiently illuminated: now all other circumstances being the same, the nearer an object is, and the brighter its colour, the more light the eye receives from it; this is one reason why near objects are more distinctly seen than those that are more remote.

2. The geometrical image of objects should fall either upon the retina, or very near it, and these images should be sufficiently large, otherwise the parts of the object cannot be distinctly perceived: the want of size in this image is also a cause of the indistinctness of remote objects.

3. It

3. It is also requisite that the eye be in perfect order, and it's humours transparent, in order that the impressions of light may be lively and distinct.

In a given eye, and a given disposition of that eye, an image upon the retina will be most perfect when the object is at some determinate distance from the eye; and it is near this point or place, that objects, if they are not too small, will be distinctly seen. An object at a greater or less distance, will have it's image either before or behind the retina; and in either case, if the distance of the image from the retina be considerable, the vision will be indistinct.

Dr. Jurin has, however, shewn that it is not necessary to distinct vision, that the images of objects, or the points of union of the rays, be precisely upon the retina, there being some latitude both before and behind the retina, within which, whatever images be formed, the vision will be equally distinct; and this latitude will be greater or less, according as the visual angles subtended by the respective objects, are greater or less.

Let a printed page, in which there are letters of three or four different sizes, be placed at such a distance, that every sort of print may, without any straining or effort of the eye, be perfectly distinct; in this case it may be reasonably presumed, that the images of the several letters fall upon the retina. If the printed leaf be brought gradually nearer and nearer, the smallest print will first begin to be confused, whilst the larger remains as distinct as before: by advancing it still nearer, the smaller print will become more confused, the next size above it a little confused, whilst the large print is still as legible as before; and so through several degrees, till the whole is in confusion.

The same experiment may be made the contrary way, by using a pair of spectacles, of a proper

convexity. From hence it is evident, that we may have distinct vision, when the focuses of the pencils are at some distance, either before or behind the retina, and that the larger the object, the greater is this latitude.

But as in this case the pencils from every point either meet before they reach the retina, or tend to meet beyond it, the light that comes from them must cover a circular spot upon it, and will, therefore, paint the image larger than perfect vision would represent it: and consequently, every object, placed either too near or too remote for perfect vision, will appear larger than it is, by a penumbra of light, caused by the circular spaces, which are illuminated by pencils of rays proceeding from the extremities of the objects. These circular spaces are called circles of dissipation. This accounts for short-sighted persons finding near objects appear rather magnified, when they use a concave that is not so deep as that to which they are accustomed.

On account of these penumbrae, it is clear that two stars will appear to be nearer than they really are; and if they be really very near, will appear to be but one, but brighter than either of them taken alone: so that the two stars will have the same appearance as if one brighter star appeared in the middle of the space occupied by two stars.

When objects are large, they will appear tolerably distinct at a much less distance than small objects, because the penumbrae will not interfere so much. For this reason, a large print may be read much nearer the eye than a small one; the former will appear only ill-defined, but sufficiently distinct, when the latter is quite indistinct, the penumbra of one letter interfering with that of another.

It is very difficult to ascertain precisely the natural distance of distinct vision, or that distance

at which the eye, without any strain or effort, is suited to see objects distinctly. If we suppose this distance to be that at which we usually read a large fair print, this will be about fifteen or sixteen inches, and less it cannot be, as we are rather more concerned with large objects than the letters of a book; and when we view objects nearer, it is on account of their minuteness: nor is it probable that the distance can be many feet, as, in order to examine objects, we are always desirous to have them near the eye, except they are very large. The nearest distance of distinct vision is in general computed to be about seven or eight inches from the eye. *That point in any object, to which the optic axis is directed, is seen more distinctly than the rest.* The truth of this position is confirmed by every one's experience: if we turn our eyes directly toward one particular part of an object so as to look steadily at it, we may indeed, if the object be not very large, see all the rest of it at the same time; but this part will appear more distinct than the rest: but looking steadily at an object is turning our optic axis towards it.

OF THE CHANGE IN THE CONFORMATION OF THE EYE FOR DISTINCT VISION, AT DIFFERENT DISTANCES.

As a ship requires a different trim for every variation of the direction and the strength of the wind, so, if we may be allowed to borrow that word, the eyes require a different trim for every degree of light, and for every variation in the distance of the object, while it is within certain limits. The eyes are trimmed for a particular object, by contracting certain muscles, and relaxing others; as the ship is trimmed for a particular wind, by drawing some ropes, and slackening others. The

sailor learns this trim of his ship, as we learn the trim of our eyes, by experience.*

A ship, although it be the noblest machine that human art can boast, is far inferior to the eye; for it requires art and ingenuity to navigate her, and the sailor must know what ropes to pull, and which to slacken, to accommodate her to a particular wind. But the eye is fabricated with such superior wisdom, and the principles of it's motion so contrived, that it requires no art nor ingenuity to see by it: we have not to learn what muscles we are to contract, nor which we are to relax, in order to fit the eye to a particular distance of the object,

But although we are not conscious of the motions we perform, in order to fit the eyes to the distance of the object, we are conscious of the effort employed in producing these motions, and probably have some sensation which accompanies them, and to which we give as little attention as to many other sensations; and thus a sensation, either previous or consequent upon that effort, comes to be conjoined with the distance of the object which gave occasion to it, and by this conjunction becomes one of the signs of that distance.

That we are capable of viewing objects with nearly equal distinctness, though they be placed at considerable distances from each other, is evident; but the alteration which takes place in the eye for this purpose, or the mechanism by which this effect is produced, is not easily ascertained.

It seems clear from the first view of the subject, that when several objects are at different distances before us, they will not appear equally distinct at the same time. Lest it should be suspected that the indistinctness in this case may be owing to the impressions not being made upon the corresponding

* Reid's Inquiry into the Human Mind.

ponding fibrils of the two retinas, let us make a trial with one eye alone, while the other is shut: thus place two small objects, as two pins, one behind the other, and let the one be at a foot, and the other at about six inches distance from the eye. Either of these objects, when looked at attentively, will appear distinct; but the other, at the same time, although it be in the axis of the eye, will be confused. And from hence it is very clear, that the same conformation of the eye is not adapted for distinct vision at all distances, and that the eye by some means changes it's conformation, so as it may be better suited for vision at different distances.

In a similar manner to the foregoing experiment, if the eye looks attentively upon the little scratches or particles of dust upon a window-glass, the objects without doors will be indistinct; and when we look at the external objects, the opaque particles upon the glass, which before were distinct, will now be confused. It also frequently happens, that when we first look at an object, it will appear very confused, which confusion will vanish by degrees, and in a little time the object will become quite distinct.

In like manner, if after poring some time on a book, we suddenly look at objects farther off, they will at first appear confused, and become distinct by degrees. A similar indistinctness takes place, when from looking at remote objects, we suddenly look at one that is near. To what can we attribute these phenomena, but to a change in the conformation of the eye for vision at these different distances? a change which requires some small time for it's performance. It cannot be owing to the last impression on the eye not being obliterated; for in that case, the same confusion would be observable upon shifting the eye from one page of a book to the other.

These phenomena are stronger when they happen without our thinking upon them; for when we make the experiment on purpose, and the mind is already prepared for what is to happen, it has time in part to frustrate our design; the more so, as these changes are somewhat painful.

Authors are much divided in their opinions concerning the change that is made in the conformation of the eye, to procure distinct vision at different distances; some thinking it to be a change in the length of the eye, others that it is a change in the figure or position of the crystalline humour, others that it is a change in the cornea. The authors of each opinion have their objections to all the rest, and perhaps the truth may lie among them all. As the rays of light suffer a greater refraction at the cornea than they do afterwards, it is plain that a less change, as to quantity, in the radius of the cornea, will effect the business, than would be sufficient in any other part of the eye: but at the same time it must also be confessed, that most persons who have been couched for cataracts, are obliged to have glasses of different convexities, in order to have distinct vision at different distances; from whence it seems necessarily to follow, that the crystalline humour is concerned in changing the conformation of the eye. Perhaps the cornea, and the crystalline, if not some other parts of the eye besides, may contribute to produce this effect: and in order to obtain distinct vision at a nearer distance, at the same time the cornea is rendered more convex, the axis of the eye may be a little lengthened, the crystalline made more convex and brought forwarder, all which changes conspire to the same end; and the contrary for obtaining vision at a greater distance.

It has been shewn by writers on optics, that if an object be viewed distinctly at three different distances

distances from the eye, the first of which may be the least distance at which it can be viewed distinctly, the second double the first, and the third infinite, the alterations in the conformation of the eye, necessary for viewing an object distinctly at the first and second distances, whose difference is but small, are as great as those that are necessary for the second and third, whose difference is infinite.

Hence, if a short-sighted person can read a small print distinctly, at two different distances, whereof the larger is but double the lesser, as great alterations are made in his eyes, as in one whose eyes are perfect, and that can see distinctly at all intermediate distances, between infinity and the largest of the two former distances. For the same reason, a short-sighted person can see distinctly at all distances, with a single concave of a proper figure; for the cause of short-sightedness is not a want of power to vary the conformation of the eye, but that the whole quantity of refractions is always too great for the distance of the retina from the cornea.

We may hence also clearly perceive why our eyes are so often fatigued in looking at near objects; for in this case, the muscles of the eyes, and the ligamentum ciliare, are obliged to make a considerable effort, to give the eyes the necessary conformation; which effort being greater in proportion as the object is nearer, must be painful and laborious when the object is very nigh.

When the eye has been attentively fixed on an object at some determined distance, it cannot immediately see another object distinctly; whether it be at a greater or lesser distance, it appears confused and imperfect, till the eye has adapted itself to the distance at which the object is placed.

OF THE PUPIL OF THE EYE, AND OF IT'S MOTIONS.

In speaking of the structure of the eye, we have shewn that the uvea has a small round hole nearly in the middle, called the *pupil*, through which the rays must all pass before they can get to the bottom of the eye, and paint the images of objects on the retina. The consideration of the various affections of this part of the eye, will be found of great importance, both to the vender and purchaser of spectacles; for upon the state and aperture of the pupil, the requisite degree of magnifying power very much depends.

The author of nature has proportioned the magnitude of the pupil, so that it may best answer the purposes of vision, and the sensibility of the retina: if it were too large, the retina would be fatigued, and hurt by the great quantity of light. Hence it is that those creatures cannot bear the light of day, which, in order to search for and procure their food at night, have the pupil of their eyes very large. Further, if this aperture had been much larger than it really is, the eye would not have been a dark cell, and so much adventitious light would have entered, as to render the picture upon the retina obscure and indistinct: for as in the camera obscura, the pictures are most lively and perfect when all the light is excluded, but what comes from the object, and serves to form the picture; so it is with our eyes; the picture on the retina is most perfect when all the extraneous light is excluded, and none mixes with the picture, but what tends to it's formation.

On the other hand, if the pupil had been very small, it would not have admitted a sufficient quantity of light; the impression on the retina would have been weak, and the picture faint and obscure; when

when the pupil is very small, convex glasses are necessary, in order to increase the quantity of light.

All animals have a power of contracting and dilating the pupil of their eyes. The natural state appears to be that of dilatation, and the contraction a state of violence, produced by an effort originating in the mind. When the light is too strong, or the object too bright, we contract the pupil, to intercept that part of the light which would injure the eye; but when the light is weak, we dilate the pupil, that more light may enter the eye. If a person look towards the sun, you will observe the pupil become exceeding small; but if he turns his eyes from the light, and be gradually brought into a dark place, you will observe the pupil to dilate, in proportion as the light becomes more faint and obscure.

There are also other circumstances which will cause the pupil to contract, as when the object is nearer the eye than the limits of distinct vision: for in this case, the pencils of rays proceeding from the object are too diverging to be united in corresponding points on the retina; but by contracting the pupil, many of the rays are excluded, and the picture is rendered more distinct. It is for this purpose, that many short-sighted persons contract a habit of corrugating their eyebrows in reading, a habit which would be prevented by the use of concave spectacles.

Dr. Jurin has shewn, that the contraction of the pupil does, in general, depend more upon the strength of the light, than on the sensation of confusion in the object. Let any person take a book by day-light, and stand near the middle of a room, with his back to the light, and then hold the book so near that the letters may appear indistinct, but not so much so, but that they may be read, though with difficulty; on turning towards the light, it

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will be read with more ease. Again, holding the book at the same distance, go into the darkest part of the room, and standing with your back to the light, you will find the book not at all legible; but on coming to the window, with your face to the light, you will be able to read with ease and distinctness. A person who has used spectacles for some years, will in the sun-shine be able to read without them.

When we have been for some time in a place much illuminated, or if the eye has been too long exposed to a resplendent object, and then views objects that are less so, or goes into a darker place, the sight will for a little time be impaired, and the eye unable to perform it's proper functions. The same will also happen from the contrary circumstances, if we go from a faint light into one that is much brighter; in either case the pupil has not time to conform itself to the sudden,* but necessary change, for seeing distinctly under the new circumstances. From hence we may infer, that very opaque shades round a candle, instead of preserving and protecting the eye, must be necessarily prejudicial to it. A moderate degree of opacity in the shade, as that of thick paper, may, by lessening the degree of light, be useful to eyes which are inflamed, or have a tendency to inflammation.

There is a kind of sympathy, or concord, in the motion of the pupils of both eyes, so that when one is contracted, the other contracts also; when one is dilated, the other also dilates, though neither the dilatation nor contraction are equal. Many
gross

* This is what Porterfield and some others say; but from other experiments, the pupil is never so contracted as in the case of going suddenly from a faint to a bright light: the contraction is instantaneous. The effects, therefore, spoken of above, must be referred to the different states of the sensibility of the retina.

gross oversights have arisen, and some dangerous mistakes have been made, by oculists, according to Porterfield, from their not attending to this fundamental law concerning the pupil.

From this expanding and contracting power of the eye, we may learn, why the eye sees best when surrounded with darkness; for the pupil, by dilating, accommodates itself as much as possible to the quantity of light, dilating considerably when the eye is in darkness, and, *cæteris paribus*, objects are seen most clearly when the pupil is most dilated. Besides, when the eye is in the dark, the picture on the retina is neither confused nor disturbed by adventitious rays: hence, those who are in a very bright light, when they want to distinguish accurately a distant object, either depress the eyebrows, or apply the hand to the forehead: hence also, a person, by placing himself in the dark, and employing a long tube, will form a species of telescope, producing a greater effect than might at first be conceived: it was on this principle that the ancients used a deep pit, in order to see the stars in the day-time. From hence we also learn, why a person from within a chamber can perceive the objects that are without, while those that are out of doors cannot see the objects that are within: for when we are out of doors, the pupil is contracted, and only a small portion of the light that is reflected from the objects within the chamber, can pass to the retina; while on the contrary, those within have the pupil more dilated, and the objects that are without are also more strongly illuminated; besides which, their view of objects is not so much obstructed by the reflection of the window-glass.

It is surprising how far the eye can accommodate itself to darkness, and make the best of a gloomy situation. When first taken from the light, and brought into a dark room, all things disappear;

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or if any thing is seen, it is only the remaining radiations that still continue in the eye; but after a very little time, the eye takes advantage of the smallest ray, which is confirmed by the following curious account, related by Mr. Boyle. In the time of Charles the first, there was a gentleman, who, sharing in his worthy master's misfortunes, was forced abroad; at Madrid, in attempting to do his king a signal service, he failed; in consequence of this, he was confined in a dark and dismal dungeon, into which the light never entered, and into which there was no opening but by a hole at the top, down which the keeper put his provisions, presently closing it again. The unfortunate loyalist continued for some weeks in this dark dungeon, quite disconsolate; but, at last, began to think he saw some glimmering of light: this dawn of light increased from time to time, so that he could not only discover the parts of his bed, and such other large objects, but, at length, he could perceive the mice that frequented his dungeon, to eat the crumbs that fell upon the ground. When set at liberty, he could not, for some days, venture to leave his cell, lest the brightness of the light should blind him; but was obliged to accustom his eyes, by slow and gradual degrees, to the light of the day.

OF IMPERFECT SIGHT.

There is no branch of science, of which it is more important that a general knowledge should be diffused, than that part which treats of the various imperfections of sight, and the remedies for them. To relieve an organ which is the source of the most refined pleasure, is certainly a desirable object: to enable those who are in want of assistance, to determine whether spectacles will be advantageous

vantageous or detrimental, and what kind will best suit their sight; and so instruct those who already use glasses, that they may discover whether those they have chosen are adapted to the imperfection of their sight, or are such as will increase their complaint, and weaken their eyes; are subjects worthy the consideration of every individual, and constitute the principal business of the remainder of this Lecture: to this end I shall, in the first place, explain what I mean by an imperfection of sight.

The sight is relatively imperfect, when we cannot see an object distinctly in a common light, and at all the usual distances at which it is observed by an eye in a perfect state.

In this sense, both the long and short-sighted are said to have an imperfect sight. The short-sighted see distant objects confusedly, those that are near at hand distinctly; their sight is therefore defective with respect to distant objects: on the other hand, the long-sighted see distant objects distinctly, near objects confusedly.

An imperfect sight is occasioned by a confusion in the image formed upon the retina; this happens whenever all the rays that proceed from any one point of an object, are not united again in one, but fall on different points of the retina: or whenever several pencils of light, from different points of an object, terminate upon one point of the image. This species of confusion takes place both in long and short-sighted eyes.

OF OLD OR LONG-SIGHTED EYES.

To detail those circumstances which are, in general, marks of advancing age, and always of partial infirmity, must be ever unpleasant, and would be equally unnecessary, if it were not the mean

mean of lessening the inconveniences attendant on those stages of life.

By the long-sighted, remote objects are seen distinctly, near ones confusedly; and in proportion as this defect increases, the nearer objects become more indistinct, till at length it is found almost impossible to read a common-sized print without assistance. An imperfect and confused image is formed upon the retina, because the rays of light that come from the several points of an object, at an ordinary distance, are not sufficiently refracted, and therefore do not meet upon the retina, but beyond it.

Various are the causes which may occasion this defect; if the convexity of the cornea be lessened, or if either side of the crystalline becomes flatter, this effect will be produced; if the retina be not sufficiently removed from the cornea or crystalline, or if the retina be too near the cornea or crystalline, it will give rise to the same defect, as will also a less refractive power in the pellucid parts of the eye; in like manner, too great a proximity of the objects, will prevent the rays from uniting till they are beyond the retina; but if all these causes concur together, the effect is greater. This defect is, however, in general, attributed to a shrinking of the humours of the eye, which causes the cornea and crystalline to lose their original convexity, and to become flatter; the same cause will bring the retina too near the cornea.

By one or other of these causes, those who were accustomed in their youth to read a common size print, at about twelve or fourteen inches distance from their eyes, are obliged to remove the book to two or three feet before they can see the letters distinctly, and read with comfort. But in proportion as the object is removed from the eye,
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the image thereof on the retina becomes smaller, and consequently small objects will not always be perceivable at that distance, to which those in this state find it necessary to remove them, in order to attain any degree of distinct vision: the further also the object is removed, the less light will enter the eye, and the image will, of course, be fainter.

Hence, those who are long-sighted require more light to enable them to read, than they did while their eyes were in their perfect state; and this not only because they are obliged to remove the book to a greater distance, but because the pupil of their eye is smaller, and therefore a greater intensity of light is necessary to produce a sufficient impression on the retina, and compensate for the defect by a greater splendor and illumination of the object.

Increasing years have a natural tendency to bring on this defect, and earlier among those who have made the least use of their eyes in their youth; but whatever care be taken of the sight, the decays of nature cannot be prevented: the humours of the eye will gradually waste and decay, the refractive coats will become flatter, and the other parts of the eye more rigid and less pliable; thus the latitude of distinct vision will become contracted: it is also highly probable, that the retina and optic nerve lose a portion of their sensibility.

Though it is in the general course of nature, that this defect should augment with age, yet there are not wanting instances of those who have recovered their sight at an advanced period, and have been able to lay aside their glasses, and read and write with pleasure, without any artificial assistance. Among many causes which may produce this effect, the most probable is, that it ge-

nerally arises from a decay of the fat in the bottom of the orbit; the pressure in this part ceasing, the eye expands into somewhat of an oval form, and the retina is removed to a due focal distance from the crystalline.

It is a certain and very important fact, that long-sightedness may be acquired; for countrymen, sailors, and those that are habituated to look at remote objects, are generally long-sighted, want spectacles soonest, and use the deepest magnifiers: on the other hand, the far greater part of the short-sighted are to be found among students, and those artists who are daily conversant with small and near objects; every man becoming expert in that kind of vision, which is most useful to him in his particular profession and manner of life: thus the miniature painter, and engraver, see very near objects better than a sailor; but the sailor perceives distant objects better than they do; the eye in both cases endeavouring to preserve that configuration to which it is most accustomed. In the eyes, as well as other parts of the body, the muscles, by constant exercise, are enabled to act with more ease and power, but are enfeebled by disuse; the elastic parts also, if they are kept too long stretched, lose part of their elasticity; while on the other hand, if they be seldom exercised, they grow stiff, and are not easily distended. From the consideration of these facts, we may learn, in a great measure, how to preserve our eyes; by habituating them occasionally to near as well as distant objects, we may maintain them longer in their perfect state, and be able to postpone the use of spectacles for many years; but we may also infer from the same premises, that there is great danger, when the eyes are become long-sighted, of deferring too long the use of spectacles, or using those that magnify too much,

much, as we may by either method so flatten the eye, as to lose entirely the benefits of naked vision. It may not be improper in this place to remark, that the long-sighted eye is much more liable to be injured by too great a degree of light, than those that are short-sighted.

Objects that appear confused to the long-sighted, will be rendered more distinct, if they view them through a small hole, such as that made by a pin in a card, because it excludes those diverging rays which are the principal source of confusion; but as it, at the same time, intercepts a considerable portion of the light, it is by no means an adequate remedy. The best relief they can obtain is from convex glasses, for by these the rays of light that proceed from the object, are so refracted, as to fall upon the retina, in the same manner as if they issued from a distant point. Spectacles afford two advantages, for they not only render the picture of objects distinct upon the retina, but they also make it strong and lively.

OF SPECTACLES.

Spectacles restore and preserve to us one of the most noble and valuable of our senses; they enable the mechanic to continue his labour, and earn a subsistence by the work of his hand, till the extreme of old age. By their aid the scholar pursues his studies, and recreates his mind with intellectual pleasures, and thus passes away days and years with delight and satisfaction, that might otherwise have been devoured by melancholy, or wasted by idleness.

As spectacles are designed to remedy the defects of sight, it is natural to wish, that the materials of which they are formed should be as

perfect as the eye itself; but vain is the wish, for the materials we use, like every thing human, are imperfect, and yet we may deem ourselves happy, to have in glass a substitute so analagous to the humours of the eye, a substance which gives new eyes to decrepid age, and enlarges the views of philosophy. The two principal defects are, small threads or veins in the glass, and minute specks. The threads are most prejudicial to the purposes of vision, because they refract the rays of light irregularly, and thus distort the object, and fatigue the eye; whereas the specks only lessen the quantity of light, and that in a very small degree.

GENERAL RULES FOR THE CHOICE OF SPECTACLES.

The most general, and perhaps the best rule that can be given, to those who are in want of assistance from glasses, in order so to choose their spectacles, that they may suit the state of their eyes, is to prefer those which shew objects nearest their natural state, neither enlarged nor diminished, the glasses being near the eye, and that give a blackness and distinctness to the letters of a book, neither straining the eye, nor causing any unnatural exertion of the pupil.

For no spectacles can be said to be properly accommodated to the eyes, which do not procure them ease and rest; if they fatigue the eyes, we may safely conclude, either that we have no occasion for them, or that they are ill made, or not proportioned to our sight.

Though, in the choice of spectacles, every one must finally determine for himself, which are the glasses through which he obtains the most distinct vision; yet some confidence should be placed in the judgment of the artist, of whom they

they are purchafed, and ſome attention paid to his directions.

OF PRESERVERS, AND RULES FOR THE PRESERVATION OF THE SIGHT.

Though it may be impoſſible to prevent the abſolute decay of fight, whether ariſing from age, partial diſeaſe, or illneſs, yet by prudence and good management, it's natural failure may certainly be retarded, and the general habit of the eyes ſtrengthened, which good purpoſes will be promoted by a proper attention to the following maxims.

1. Never to fit for any length of time in abſolute gloom, or expoſed to a blaze of light. The reaſons on which this rule is founded, prove the impropriety of going haſtily from one extreme to the other, whether of darkneſs or of light, and ſhew us, that a ſouthern aſpect is improper for thoſe whoſe fight is weak and tender.

2. To avoid reading a ſmall print.

3. Not to read in the duſk; nor, if the eyes be diſordered, by candle-light. Happy thoſe who learn this leſſon betimes, and begin to preſerve their fight, before they are reminded, by pain, of the neceſſity of ſparing them; the frivolous attention to a quarter of an hour of the evening, has coſt numbers the perfect and comfortable uſe of their eyes for many years: the miſchief is effected imperceptibly, the conſequences are inevitable.

4. The eye ſhould not be permitted to dwell on glaring objects, more particularly on fiſt waking in a morning; the ſun ſhould not of courſe be ſuffered to ſhine in the room at that time, and a moderate quantity of light only be admitted. It is eaſy to ſee, that for the ſame

reasons, the furniture of a bed should be neither altogether of a white or red colour; indeed, those whose eyes are weak, would find considerable advantage in having green for the furniture of their bed-chamber. Nature confirms the propriety of the advice given in this rule: for the light of the day comes on by slow degrees, and green is the universal colour she presents to our eyes.

5. The long-sighted should accustom themselves to read with rather less light, and somewhat nearer to the eye than what they naturally like; while those that are short-sighted, should rather use themselves to read with the book as far off as possible. By this means, both would improve and strengthen their sight; while a contrary course will increase it's natural imperfections.

There is nothing which preserves the sight longer, than always using, both in reading and writing, that moderate degree of light which is best suited to the eye; too little strains them, too great a quantity dazzles and confounds them. The eyes are less hurt by the want of light, than by the excess of it; too little light never does any harm, unless they are strained by efforts to see objects, to which the degree of light is inadequate; but too great a quantity has, by it's own power, destroyed the sight. Thus many have brought on themselves a cataract, by frequently looking at the sun, or a fire; others have lost their sight, by being brought too suddenly from an extreme of darkness into the blaze of day. How dangerous the looking upon bright luminous objects is to the sight, is evident from it's effects in those countries which are covered the greater part of the year with snow, where blindness is exceeding frequent, and where the traveller
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is obliged to cover his eyes with crape, to prevent the dangerous, and often sudden effects of too much light: even the untutored savage tries to avoid the danger, by framing a little wooden case for his eyes, with only two narrow slits. A momentary gaze at the sun, will, for a time, unfit the eyes for vision, and render them insensible to impressions of a milder nature.

The following cases from a small tract on the "*Fabric of the Eye*," are so applicable to the present article, as to want no apology for their insertion here; though if any were necessary, the use they will probably be of to those whose complaints arise from the same or similar causes, would, I presume, be more than sufficient.

"A lady from the country, coming to reside in St. James's-square, was afflicted with a pain in the eye, and a decay of sight. She could not look upon the stones, when the sun shone upon them, without great pain. This, which she thought was one of the symptoms of her disorder, was the real cause of it. Her eyes, which had been accustomed to the verdure of the country, and the green of the pasture grounds before her house, could not bear the violent and unnatural glare of light reflected from the stones; she was advised to place a number of small orange trees in the windows, so that their tops might hide the pavement, and be in a line with the grass. She recovered by this simple change in the light, without the assistance of any medicine; though her eyes were before on the verge of little less than blindness."

"A gentleman of the law had his lodgings in Pall-mall, on the north-side, his front windows were exposed to the full noon sun, while the back room, having no opening, but into a small close yard, surrounded with high walls, was very dark;

he wrote in the back room, and used to come from that into the front to breakfast, &c. his sight grew weak, and he had a constant pain in the balls of his eyes; he tried visual glasses, and spoke with oculists, equally in vain. Being soon convinced, that the coming suddenly out of his dusky study, into the full blaze of sun-shine, and that very often in the day, had been the real cause of his disorder; he took new lodgings, by which, and forbearing to write by candle-light, he was very soon cured."

Blindness, or at least miserable weakneses of sight, are often brought on by these unsuspected causes. Those who have weak eyes, should therefore be particularly attentive to such circumstances, since prevention is easy, but the cure may be difficult, and sometimes impracticable.

Whatsoever care, however, be taken, and though every precaution be attended to with scrupulous exactness; yet as we advance in years, the powers of our frame gradually decay; an effect which is generally first perceived in the organs of vision.

Age is, however, by no means an absolute criterion, by which we can decide upon the sight, nor will it prove the necessity of wearing spectacles. For, on the one hand, there are many whose sight is preserved in all its vigour, to an advanced old age; while, on the other, it may be impaired in youth by a variety of causes, or be vitiated by internal maladies. Nor is the defect either the same in different persons of the same age, or in the same person at different ages; in some the failure is natural, in others it is acquired.

From whatever causes this decay arises, an attentive consideration of the following rules will enable every one to judge for himself, when his sight may be assisted or preserved by the use of spectacles.

I. When

1. When we are obliged to remove small objects to a considerable distance from the eye, in order to see them distinctly.

2. If we find it necessary to get more light than formerly; as for instance, to place the candle between the eye and the object.

3. If on looking at, and attentively considering a near object, it becomes confused, and appears to have a kind of mist before it.

4. When the letters of a book run one into the other, and hence appear double and treble.

5. If the eyes are so fatigued by a little exercise, that we are obliged to shut them from time to time, and relieve them by looking at different objects.

When all these circumstances concur, or any of them separately take place, it will be necessary to seek assistance from glasses, which will now ease the eyes, and in some degree check their tendency to grow flatter; whereas if they be not assisted in time, the flatness will be considerably increased, and the eyes be weakened by the efforts they are compelled to exert.

We are now able to decide upon a very important question, and say how far spectacles may be said to be *preservers of the sight*. It is plain they can only be recommended as such, to those whose eyes are beginning to fail; and it would be as absurd to advise the use of spectacles to those who feel none of the foregoing inconveniences, as it would be for a man in health to use crutches to save his legs. But those who feel those inconveniences, should immediately take to spectacles, which, by enabling them to see objects nearer, and by facilitating the union of the rays of light on the retina, will support and preserve the sight.

OF COUCHED EYES.

With the diseases of the eye, these Lectures have no concern; they have been already well and ably considered by professional men; and it is scarce necessary to observe, that in anatomical knowledge, and in the practical operations of surgery, England now claims a just pre-eminence over other nations.

But among the various diseases of this organ, there is one in which, after the surgeon has quitted the patient, glasses are necessary, to give effect to the operation, and a comfortable sight of objects to the person relieved. This disease is the cataract, a disorder affecting the crystalline humour of the eye; when the opacity is confirmed, this humour becomes so opake, as scarcely to admit any rays of light, and prevents their producing their ordinary effects, and consequently no image of any object is formed, though the retina, and other organs of sight, are in perfect order. There is no disorder more deplorable in it's nature and consequences; destructive of the sight, often beyond the reach of remedy: the hand of the operator is the only hope, and his efforts are sometimes unsuccessful.

The cause of this disorder is seldom known. Sometimes it has been thought to be brought on by frequent inspection of the sun, and sometimes by looking too long and too often at a bright fire. In early stages of the disease it has been thought to be removed by medicine.* Of the various remedies

* Baron de Wenzel, in his Treatise on the Cataract, denies that any medicine has power to dissipate the opake crystalline. Mr. Ware, in his translation of this work, assents to the truth of the Baron's observation, so far as is at present known; but adds, that many cases have occurred, under his own inspection, which prove that the powers of nature are often sufficient for this purpose. Those opacities in particular, which are produced by external

medies that have been used for this purpose, the electrical stream is supposed by many to be the best, on account of it's powerful discutient properties.

The assistance the eye receives from the surgeon is either by depression of the crystalline below the pupil, or extracting the cataract. But as the density of the vitreous humour, which supplies the place of the crystalline, is less, the rays of light will be less refracted, and not meet at the retina, but at some distance behind it; the sight will therefore be imperfect, except the eye be assisted with a proper convex glass. There is a circumstance attending couched eyes, which fully evinces that the change made in our eyes, to accommodate them to the distances of objects, must be principally attributed to the crystalline humour; namely, that one focus is seldom sufficient to enable those who have undergone this operation, to see objects at different distances. They generally require two pair of spectacles, one for near, the other for more distant objects. The foci that are used lie between 6 and $1\frac{1}{2}$ inches.

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nal violence, he has repeatedly seen dissipated in a short space of time, when no other parts of the eye have been hurt; and in general, in cases of this description, the crystalline humour has been dissolved; which has been demonstrated, by the benefit the patient has afterwards derived from adopting the use of deeply convex glasses. Mr. Ware adds, that instances are not wanting, in which cataracts, which were formed without any violence, have been suddenly dissipated, in consequence of an accidental blow on the eye. For these reasons he entertains a hope, that means may hereafter be discovered, by which an opaque crystalline may be rendered transparent, without the performance of any operation whatever. The remedies which have appeared to Mr. Ware more effectual than others, in these cases, have been the application to the eye itself of one or two drops of æther, once or twice in the course of the day, and the occasional rubbing of the eye over the lid, with the point of the finger, first moistened with a weak volatile or mercurial liniment. See Ware's translation of Wenzel's Treatise on the Cataract, page 13.

It is not adviseable to use glasses too soon after the operation; for while the eyes are in a debilitated state, all exertions are not only improper, but also very prejudicial.

OF THE SHORT-SIGHTED.

In this defect of the eyes, the images of objects at an ordinary distance unite before they arrive at the retina, and consequently the images formed thereon are confused and indistinct. This effect is produced either by too great a convexity in the cornea and crystalline, or too great a refractive power in the humours of the eye; or the retina may be placed too far; or it may arise from a concurrence of all these circumstances.

Those who are short-sighted can distinguish smaller objects, and see clearly a given small object with less light than other people: the reason is evident, for the nearer the object is, the more light enters the pupil; being also more dense, it's action is more powerful on the retina; hence the short-sighted can read a small print by moon-shine, or in the twilight, when a common eye can scarce distinguish one letter from another.

In a strong light they can see a little farther than they do when it is weak; the strength of the light causes the pupil of their eyes to contract, and thus removes in some degree the indistinctness of the objects. Upon the same principle we may account for the short-sighted so often partly shutting their eyelids, from whence they were formerly denominated *myopes*; by this means, they confine the bases of the pencils of rays which issue from the points of an object, and thus contract the circle of dissipation, and lessen the indistinctness of vision: hence they also see objects more distinctly through a small hole, as that made by a pin in a card.

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It is a common observation, that the short-sighted do in general prefer a small print to a large one, and that they usually write a small hand; for by the proximity the letters are magnified, and, being small, they take in a greater number at one view; they hold the book they are reading in generally inclined to one side, in order to attain a greater degree of illumination. As they can only see distinctly objects that are near, they are obliged, by a strong effort of the mind, to cause the axes of the eyes to converge; this effort being painful, forces them often to turn away one of their eyes, which producing double vision, they are obliged to shut it. When they hold a book directly before their eyes, the picture will fall upon the middle of the retina; but if they hold it obliquely, it will fall upon the side of the retina; now the middle of the retina is further from the fore part of the eye than the side of it is. Therefore though the picture be so near to the fore part of the eye as to be confused if it fall upon the middle, it may be distinct when it falls upon the side.

As those who are very short-sighted do not perceive the motion of the eyes and features, they seldom look attentively at those with whom they are conversing: it is from this circumstance that Pliny terms the prominent-eyed *hebetiores*; not that this defect in sight impairs genius, or lessens the powers of the mind; but as it deprives them of the rapid communications that are made by the eye, it apparently lessens that vivacity of conception, which always accompanies a vigorous mind.

Happily for the short-sighted, the principal inconveniences of their sight may be remedied by the use of concave glasses; by their assistance, those whose sphere of distinct vision scarce extended beyond their arm, are enabled to distinguish,

guish, very satisfactorily, objects at a considerable distance; the concave lens produces distinct vision, by causing the rays to diverge more, and unite at the retina, instead of meeting before they reach the bottom of the eye.

In the choice of glasses for the short-sighted, no rules can be laid down; it is a defect that has no connection with age, no stated progression that can be a foundation to guide the optician, or lead him to recommend one glass in preference to another; the whole must depend on the observation of the short-sighted themselves, who, by trying glasses of different degrees of concavity, will soon find out that whose effects are most advantageous, producing distinct vision at different distances.

If the short-sighted person is so far removed from an optician, as not to have an opportunity of trying a variety of lenses, he may be nearly suited, by sending to him the greatest distance at which, with his naked eye, he can see distinctly; he will, by the following rule, be enabled to suit him with tolerable exactness.

Multiply the distance at which the short-sighted person sees distinctly with his naked eye, by the distance at which it is required he should see distinctly by a concave glass, and divide the product by the difference between the aforesaid distances: if the required distance be very remote, the glasses must be of that radius at which they see distinctly with their naked eyes.

The benefit the short-sighted receive from concave glasses, is not so great as the long-sighted find by a convex lens; for an object is not only magnified, but the eye receives also a larger pencil of light from each visible point, because the rays enter less diverging: whereas the concave not only diminishes the object in size, but it lessens

lessens also the quantity of light, as it renders the rays more diverging; consequently the short-sighted do not see remote objects, unless they are very large and bright, so well through a concave lens as theory promises: for the chief impediment to a distinct view of remote objects, is their want of light and magnitude, but both of these a concave lens increases.

It is generally supposed, that the short-sighted become less so as they advance in years, as the natural shrinking and decay in the humours of the eye lessen it's convexity, and thus adapt it better for viewing of distant objects; but among the great number of short-sighted that I have accommodated with glasses, I have ever found the reverse of this theory to be true, and the eyes of the myopes never required glasses less concave, but generally more concave as they grew older, to enable them to see at the same distance.

Further, the effects of habit, which are in most cases very powerful, but peculiarly so in the affections of the eye, have a natural tendency to increase the defect of the myopes; for by frequently looking close to objects, in order to see them distinctly, they would make themselves near-sighted, though their eyes were naturally the reverse: hence we find, that watch-makers, engravers, and studious persons, often bring on this defect. By reading or working at as great a distance as possible, and often looking at remote objects, the degree of short-sightedness may be much lessened. As children in general read much nearer than grown persons, if they are suffered to indulge this propensity, they become naturally short-sighted.

I have found it necessary, in some instances, to give convex glasses to the short-sighted, when very far advanced in age, not because their eyes were grown less convex, but to give them more light,

light, and counteract an extreme contraction of the pupil.

Great as are the disadvantages of the short-sighted, they are less, perhaps, with respect to distant objects, than is generally imagined; they see the brighter stars and planets, nearly as well as other people. They are prevented indeed from distinguishing beyond a certain small distance, the small parts of an object which are very visible to another; thus they cannot distinguish the features of a face across a room, and as objects are generally discriminated by their minuter parts, their disadvantage in viewing objects at a moderate distance is very evident. But though such a person cannot discern the minutiae of objects, unless they are very large and very near him; yet he can perceive any object in the gross, at a considerable distance, if it be not too small: thus he may perceive a man at the distance of several paces, but must advance within one or two, before he can determine who he is, or call him by his name; he will see a large tree much further, and from experience in such cases, will perceive, that a large obscure object at a great distance is an house, to the surprize of his friends who are acquainted with the nature of his sight. On these principles, we may easily account for the apparent paradox of the pur-blind, or those who can scarcely see a small object at arm's length, yet discovering those that are very remote.

LECTURE XVIII.

ON THE

NATURE OF VISION.

OF THE DISTANCE, MAGNITUDE, AND APPARENT
PLACE OF OBJECTS.

LET us now consider by what means the *mind*, assisted by the eyes, is informed of the *distance* of objects. *Distance*, of itself and immediately, is *imperceptible*; for it is only a line directed endways to the eye. Thus, if I look endways at this piece of packthread, the length of it would be invisible from it's situation, and therefore the image on the retina can only be a *point*, which point will be invariably the same at all distances; whether the object be a thousand miles, or only a foot from us, the point is still the same.

The change of conformation in the eye, is the first means whereby the eye judges of distance. If the figure of the eye and the situation of all it's parts were to continue always the same at all distances of the objects we are looking at, the picture of some objects upon the retina would be confused, because they are too far off, and others because they are too near. In viewing objects at small but different distances, the eye must change it's conformation for procuring distinct vision. Young people have commonly the power of adapting their eyes to all distances of the object, from 6 or 7 inches to 15 or 16 feet, so as to have perfect and distinct vision at any distance within these limits.

The effort they use to adapt the eye to any particular distance of objects, within that distance, will become a sign of that distance.

This change in the conformation of the eye has it's limits, beyond which it cannot go ; it can therefore be of no use to us in judging of the distance of objects that are placed beyond the limits of distinct vision. But as the object appears more or less confused, according as it is more or less removed from these distances, the degree of confusion in the objects assists the mind in judging of distances, and becomes a sign thereof considerably beyond the limits of distinct vision. This confusion has also it's bounds, beyond which the image on the retina will not be sensibly more indistinct, though the object be removed to a much greater distance.

If therefore we had no other means but this of perceiving the distance of visible objects, the most distant would not appear to be above 20 or 30 feet from the eye ; and the tops of houses and trees would seem to touch the clouds, because in that case the signs of all greater distances being the same, they have the same signification, and give the same perception of distance.

We are therefore provided with another means, namely, *the inclination of the optic axes*. In viewing an object attentively with both eyes, we always direct both eyes towards it, and the nearer the object is the more they will be inclined to each other, and the more remote the less will be this inclination : and although we are not conscious of this inclination, yet we are conscious of the effort employed in it. By this means we perceive small distances more accurately than we could do by the conformation of the eye only ; and therefore we find that those who have lost the sight of one eye, are apt, even within arm's length, to make mistakes

mistakes in the distance of objects, which are easily avoided by those who see with both eyes: such mistakes are often discovered in snuffing a candle, threading a needle, and filling a tea-cup. A person who plays well at tennis, will find himself subject to the same mistakes the first time he plays with his eye hoodwinked.

To be convinced of the truth of this observation, suspend by a thread a ring, so that the edge may be towards you, and it's hole look right and left; take a stick which is crooked at the end, and retiring 2 or 3 paces from the ring, cover one eye with your hand, and endeavour with the other to pass the crooked end of the rod through the ring: easy as the experiment may appear, you will scarcely succeed once in a hundred times if you move the rod quickly.

Although this second mean of perceiving the distance of visible objects be more exact and determinate than the first, yet it hath it's limits, beyond which it can be of no use. For when the optic axes directed to an object are so nearly parallel, that in directing them to an object yet more distant, we are not conscious of any new effort, nor have any different sensation, our perception of distance stops; and as all more distant objects affect the eye in the same manner, we perceive them to be at the same distance. This shews why the sun, moon, planets, and fixed stars, when not seen near the horizon, appear to be all at the same distance, as if they touched the concave surface of a great sphere.

The colours and degrees of brightness in objects is a cause of a difference of apparent distance. As objects become more and more remote, they gradually appear more faint, languid, and obscure; their minute parts become more indistinct; their outline less accurately defined; their colours not

only lose their lustre, but degenerate from their natural hue, and are tinged with the azure of the intervening atmosphere. It is by these means that painters can represent upon the same canvas objects at very different distances. The diminution of magnitude in an object would not be sufficient to make it appear at a great distance without this degradation of colour, indistinctness of the outline, and of the minute parts. If a painter should make a human figure, ten times less than other human figures that are in the same piece, having the colours as bright, and the outline and minute parts as accurately defined, it would not have the appearance of a man at a great distance, but of a pigmy or Lilliputian. Painters therefore, to give their figures a due degree of remoteness, are obliged to lay over each a thick colouring of air; for the more remote the object, the more do it's own colours seem lost in that of the intervening atmosphere. This is called *keeping*, for by this means every object in a picture seems to keep it's proper distance from the rest.

Dr. Smith gives us a curious observation made by Bishop Berkeley in his travels through Italy and Sicily. He observed, that in those countries, cities and palaces, seen at a great distance, appeared nearer to him by several miles than they really were; and this he attributed to the purity of the Italian and Sicilian air, which gave to very distant objects that degree of brightness and distinctness, which in the grosser air of England was only seen in those that were near. Hence a chamber appears less when it's walls are whitened, and fields and hills appear less when covered with snow.

It is also certain, that in air uncommonly pure we are apt to think visible objects nearer and less than they really are, and in air uncommonly foggy

we

we are apt to think them more distant and larger than the truth. A westerly prospect in a clear morning, with the sun upon it, appears nearer than when the sun is higher up and more westerly. The disposition of the clouds and innumerable other circumstances affect the brightness of objects, and contribute their share in forming our ideas of the distance of remote objects.

The length of the ground-plane, or number of intervening parts perceived in it, is another mean by which we perceive distance. We are so much accustomed to measure with our eye the ground we travel over, and to compare the judgment of distances formed by sight with actual experience or information, that we by degrees in this way form a more accurate judgment of the distance of terrestrial objects than we could do by any of the above-mentioned means.

A given extent appears longer according as it contains a greater number of visible parts; and hence two remote and very unequal distances may appear very unequal, according to the different circumstances of the intervening parts, and as the spectator is differently elevated. Thus a hedge having in it several grown trees, generally looks longer than a clipt hedge, or the same extent of ground in an open field. For the same reason a row of houses, columns, or trees regularly planted, appear longer than a plain wall of the same extent; for in this case there are not only more visible and remarkable parts in the one case, but our pre-knowledge of the several intervening objects being equidistant, tends to protract the apparent length of the whole chain still longer. A river at first does not look so broad as it does after you have had a side view of the bridge across; and indeed a given extent of water does not appear so long as the same extent of land, it being more difficult to distinguish

guish parts in the surface of the one, than it is in the surface of the other. Hence a person unused to a sea prospect will be much mistaken in his judgment of distances; a ship that is 8 or 10 miles from the shore, will scarce seem to him to be a mile off.

When part of the intervening chain is invisible, or obscurely seen, the apparent distances of objects that are beyond that part will be accordingly less. Thus a certain extent of rough, uneven ground, appears shorter than the same extent of plain ground; the prominent parts hiding the cavities behind them, the apparent distance is so much the less by the loss of those invisible parts. For the same reason the brow of an hill seen over the top of another frequently looks nearer than it does after the vale between presents itself to our view; and the banks of a river at some distance, will seem contiguous, if no part of the surface of the river is visible.

The known distance of the terrestrial objects which terminate our view, makes that part of the sky which is towards the horizon appear more distant than that which is towards the zenith. And hence the apparent figure of the sky is not that of a hemisphere, but rather a less segment of a sphere; and the diameter of the sun or moon, and the distance between two fixed stars, seen contiguous to a hill, or to any terrestrial object, appear much greater than when no such object strikes the eye at the same time.

When the visible horizon is terminated by very distant objects, the celestial vault is enlarged in all its dimensions. When viewed from a confined street or lane, it bears some proportion to the buildings which surround it; but when viewed from a large plain, terminated on all sides by hills rising one above another to the distance of 20 or more

more miles from the eye, you see as it were another heaven, whose magnificence declares the greatness of it's AUTHOR, and puts every human edifice out of countenance; for the lofty spires and gorgeous palaces shrink into nothing before it, and bear no more proportion to the celestial dome, than their maker to it's MAKER.

Different degrees of apparent distances are suggested by the diminution of their apparent or visible magnitude. We know, by experience, what figure a man or any known object makes to our eyes at ten feet, and we perceive a gradual diminution of the visible figure at 20, 40, 100 feet, and so on till it at last vanishes: hence a certain visible magnitude of a known object becomes the sign of a certain determinate distance, and carries with it the conception and belief of that distance.

But when we are ignorant of the real magnitude of an object, we can never from the apparent magnitude form any judgment of it's distance. Hence we are so frequently deceived in our estimate of distance, by the extraordinary magnitude of any object seen at the end of it; as, in travelling towards a large city, or a castle, or a cathedral church, or a large mountain, we imagine them nearer than we find them to be. This is also the reason why animals and all small objects, seen in vallies, contiguous to large mountains, appear exceedingly small; for we think the mountain nearer to us than if it were smaller, and we should be surpris'd at the apparent smallness of the neighbouring animals, if we thought them farther off. Hence also objects appear smaller to the eye when seen from a high building, than they seem to be when viewed from the same distance on level ground.

Let a boy, who has never been upon any high building, go to the top of the Monument, and look

down into the street, and the objects seen there will appear to him so small as to occasion much surprise. But 10 or 20 years after, if he has now and then used himself to look from that and other great heights, the object will not appear so small. For this reason statues placed upon very high buildings ought to be made of a larger size than those which are seen at a nearer distance.

OF APPARENT MAGNITUDE.

The apparent magnitude of very distant objects is neither determined by the angle under which they are seen, nor in the exact proportion of that angle compared with their true distance, but is compounded with a deception concerning that distance, insomuch that, if we had no idea of the difference in the distance of objects, each would appear in magnitude proportional to the angle under which it is seen; and if our apprehension of the distance was always just, our ideas of their magnitude would be in all distances unvaried; but in proportion as we err in our conception of distance, the greater angle suggests a greater magnitude. It is probable, *that the apparent magnitudes are either exactly or very nearly in the compound ratio of the visual angles and apparent distances.*

We are as frequently deceived in our notions of magnitude as those of distance. A fly skipping before an unattentive spectator, will sometimes excite the idea of a crow flying afar off; but as soon as the mistake in the distance is found, the crow will dwindle into a fly. Thus also, as we have observed in foggy weather and in the dusk, objects appear further off than they really are, and in these cases proportionably larger, as there is a greater mistake in the distance. Thus a small heap of
stones

stones has been mistaken for the ruins of a large building, &c.

The diminution of apparent magnitude is so very small in proportion to the greater increase of distance, that in general the visual angles subtended by objects can have but little share in forming our judgment of their distances; and indeed if the case was otherwise, it would be almost impossible for us to guess aright, either as to distance or magnitude. For instance, if we did not judge independently of the visual angle, how could we know a child from a grown person, or even a pin from a May-pole. For the largest object being removed to a greater distance may subtend an angle less than any assignable one; as objects generally appear nearer when the intervening chain is not perceived: and the same reason operates, as already observed, in making them appear proportionably smaller. Thus the distance of an object joined with it's visible magnitude, is a sign of it's real magnitude; and the distance of the several parts of an object joined with it's visible figure, becomes a sign of it's real figure.

When you look at a globe standing before you, by the original powers of sight you perceive only something of a circular form, variously coloured. The *visible figure* hath no distance from the eye, no convexity, nor hath it three dimensions; even it's length and breadth are incapable of being measured by inches, feet, or other linear measures. But when you have learned to perceive the distance of every part of this object from the eye, this perception gives it convexity, and a spherical figure; and adds a third dimension to that which had but two before. The distance of the whole object enables you also to perceive how an inch or a foot of length affects the eye at that distance: you perceive by your eye the dimensions of the globe.

So

So numerous are the relations between the eye and the understanding, between light and knowledge, that there are very few parts of optics from which you may not deduce some practical advantages. Thus the judgment of the mind corresponds with the strength and colour of the objects whereon they are passed: but the further objects are removed, they grow more faint and indistinct, and of course our opinions concerning them will be less vivid and clear. Both pleasures and pains at a distance appear scarce worth our regarding, or giving ourselves any trouble about them; the present occupies our thoughts, and forcibly carries away the preference in our imagination from the future, against the clearest and surest decisions of our understanding. To rectify this imperfection of our nature, is worthy of your utmost application; and you may easily do it by *gradually* inuring the mental eye to discern objects at a distance. It is the quickness of this *moral sense*, or an habitual full persuasion of certain good and evil, however remote, being equally valuable with the present, that constitutes the virtue of prudence.

OF APPARENT MOTION.

If two objects at different distances from the eye move in parallel lines, nearly at right angles to the optic axis, and with the same velocity, the most distant will appear to move slowest, and the nearest will appear to move quickest, because the space described by the most distant object will subtend a much smaller angle to the eye.

If the directions in which the bodies move are not parallel, the *nearest* object may appear to move slower than the more *distant*, although it really moves quicker, if the space described be situated

so obliquely to the visual rays, that they form at the eye much smaller angles, than smaller spaces described by the more distant object, which is exposed more directly to the eye.

If two objects unequally distant from the eye move with unequal velocities in the same direction, their apparent velocities are in a ratio compounded of the direct ratio of their true velocities, and the reciprocal one of their distances from the eye.

As objects in motion will have different apparent velocities at different distances; so to a spectator in motion, objects at rest will have different apparent velocities. Thus a passenger in a coach sees the trees in the next hedge move swiftly backwards, while those in the field beyond move slower, and those beyond these still slower, and so on, those that are very remote being scarce perceived to move at all. And if a spectator in motion keeps his eye fixed upon an object at some distance, objects that are pretty near to it will appear at rest, whilst nearer objects will appear to go backwards, and more remote ones progressively forward, the same way as the spectator.

If two or more objects having the same apparent velocity move all the same way, an object at rest, by which they pass, may appear to move the contrary way, while the objects in motion may appear at rest: for as their images keep the same distance upon the retina, no motion among them can be perceived. If the spectator insensibly moves his eye, so as to keep these images in the same place, the image of the object at rest will pass successively over them, in the same manner as if that object had been in motion the contrary way. The same phenomenon may happen, if the single object be in motion, either the same or the contrary way; only it's apparent motion will be quicker or slower, direct or retrograde, according to different circumstances.

stances. Thus when the clouds move successively over the moon, she seems to go with their velocity the contrary way, whether that be eastward or westward.

From hence you may see how difficult it is to form a just estimate of the real velocities of objects from apparent ones, since we ought to know both the directions and distances of the moving objects, neither of which in many cases can be guessed at with tolerable accuracy.

Bodies in motion must move with a certain degree of velocity in order to become perceptible. Though it is difficult to assign with accuracy the space that must be passed over in a given time, in order to be sensible; yet in general we may say that it should describe, in a second of time, a space that will form at the eye an angle of 15 or 20 seconds of a degree. Hence we see why the heavenly bodies are not perceived to move, the spaces described by them in a minute not subtending an angle of above $\frac{1}{4}$ degree, when their apparent motion is greatest. For the same reason we do not perceive the motion of the hour, or even the minute hand of a watch. In the same manner a prodigious great velocity, as the diurnal motion of the heavenly bodies, may be yet too slow to be perceived; and an object may move with so great a velocity as not to be perceived, as the flight of a ball out of a gun.

An object moving with great velocity is not seen unless it be very luminous. Thus a cannon ball is not seen, if it be viewed transversely; but if it be viewed according to the line it describes, it may be seen, because its picture continues long on the same place of the retina, and therefore receives a stronger impression.

As we have all been children before we were men, we have all, I doubt not, at that season amused ourselves with many childish diversions, one of which

which you may remember was burning a small stick to a live coal, and whisking it round to make gold lace, as we called it. We little thought then of making experiments in philosophy; but we may turn this innocent amusement to that use, in our riper years, by gathering from thence, that our organs can continue sensation after the impulse of objects exciting it is over: for the coal is in one point only at one time, and can be seen only where it is; yet there appears an entire circle of fire, which could not happen unless the light coming from it, at every point, put the optic nerves into a motion that lasted until the object returned to the same point again; nor, unless this motion raised the same perception in the mind as it did upon the first striking of the light. For if the stick be not twirled swiftly enough, so that it cannot make a second impression from the same point, before the motion excited by the first be over, you will not see a whole fiery ring, but a lucid spot passing successively through every part of the circle.

On the principles we have laid down, are explained what are called *fallacies in vision*. They depend principally on our mistaking the distances of objects. Thus, parallel lines, as long vistas, consisting of parallel rows of trees, seem to converge more and more as they are farther extended from the eye; because the lines which measure their intervals, and which are always equal, subtend smaller angles, the more remote they are, and so appear perpetually diminishing, while we, at the same time, mistake the distance. For the same reason, the remote parts of a horizontal walk, or a long floor, will appear to ascend gradually; and the more remote the objects are that are placed upon it, the higher they will appear,

pear, till the last be seen on a level with the eye: whereas the ceiling of a long gallery appears to descend towards a horizontal line, drawn from the eye to a spectator. And the surface of the *sea*, seen from an eminence, seems to rise higher and higher, the farther we look: and the upward parts of high buildings incline forwards over the parts below; so that statues on the top of such buildings, in order to appear upright, must recline or bend backwards.

There is another phenomenon, however, not so easily accounted for: if a person turns swiftly round, without changing his place, all objects about will seem to move round in a contrary way; and this deception continues not only while the person himself moves round, but which is more surprising, it continues also for some time after he ceases to move; *i. e.* when both the eye and the object are at rest. The first is not so difficult to explain, for the motion of the object on the retina easily explains it: but why it continues when both the eye and the object are at rest, has not yet been well understood. It appears to me, that the seat of sense is not altogether passive in receiving images, but positively directs a ray from itself to every object it perceives; the action and reaction between objects and the seat of sense, is wholly reciprocal. Hence we see objects, or their image, after the eye is turned from them. Hence, also, in a delirium, the objects of the imagination receive a real representation in the organs of sense: and hence we do not see an object the eye happens to be fixed on, if the attention be otherwise engaged.

It is, however, to be observed, with respect to what we call the *fallacies in vision*, the appearance of things to the eye always corresponds to the
fixed

fixed laws of nature; therefore, to speak properly, there is no fallacy in the senses. Nature always speaks the same language, and uses the same signs, in the same circumstances: but we sometimes mistake the meaning of the signs, either through ignorance of the laws of nature, or through ignorance of the circumstances which attend the signs.

To a man unacquainted with the principle of optics, almost every experiment that is made with the prism, with the magic lanthorn, with the telescope and the microscope, seem to produce some fallacy in vision. Even the appearance of a common mirror, to one altogether unacquainted with the effects of it, would seem most remarkably fallacious: for how can a man be more imposed upon, than in seeing that before him which is really behind him? How can he be more imposed upon, than in being made to see himself several yards removed from himself? Yet children, even before they can speak their mother-tongue, learn not to be deceived by these appearances. These, as well as all other surprizing appearances produced by optical glasses, are a part of the visual language; and to those who understand the laws of nature concerning light and colours, are in no wise fallacious, but have a distinct and true meaning.

OF VISION BY IMAGES.

The particular phenomena of vision, in given cases, by reflected and refracted light, have been the principal subject of the preceding optical Lectures: but, on account of their universality, it will be proper to make a few more observations on this subject.

Vision

Vision of real objects seen directly, and vision by images, are both founded on the same principles: that is, similar impressions, or the same kind of images upon the retina, excite similar ideas in both cases. Consequently, *objects*, when seen by reflected or refracted rays, are seen in the places of *their last images*. If these images are at moderate distances before the eye, the several circumstances by which we form the ideas of the apparent distances of objects seen by naked vision, are also taken into the account. Universally, every visible point of an object appears somewhere in the direction of the axis of the pencil of rays proceeding from it to the eye after it's last reflection or refraction.

In vision by images, we are generally deprived of many circumstances by which we usually judge of distances; and this makes it difficult, in most cases, to determine the place of an image, particularly if it be further off than two or three yards. These difficulties are frequently increased by some peculiarities appertaining to the images which we are not accustomed to, and for which we are at a loss to make the proper allowances. But when the image is within the above-mentioned limits, we can, in most cases, determine it's place with sufficient accuracy: and here, as well as in naked vision, the nearer we can determine the place from whence the rays converge to the eye, the more distinct will the image appear.

The apparent magnitudes of objects, seen by reflection or refraction, are either accurately, or very nearly, *as the rectangles under the visual angles and apparent distances of their last images*. In all cases, the apparent place, position, and figure of an object seen by refracted or reflected light, are as those of it's last image. For the rays proceeding from the image to the eye, form a succession
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of physical points after the same manner as if they came from a real object, and therefore excite an idea of an object equal and similar to the image.

Hence, as you have seen, in vision by images, we are liable to many deceptions, some of which are entertaining, as well as surprising; for not only the place of an image, but very often it's position, magnitude, and even figure, shall be quite different from the real object.

OF VISION BY IMAGES.*

As this is a subject of the greatest importance in optics, it will be worth while to consider it when stated in different words, with some additional circumstances.

When the rays in a pencil diverge from a point, and either by reflection or refraction are brought all together again, they then form a luminous point corresponding to that from which they diverged.

By this means a new *visible* object is formed, called the image of the other; for the eye now receives the rays as coming from this latter point, and therefore judges the former point to be in the place of the latter; and as this is true for every point of any object, every object may thus actually be formed a-new, so far as regards our *visible* ideas. And the rays diverging to the eye from the image thus formed, in the same manner as if they came directly from the object, excite an idea of that image, or of an object similar to it.

Now, if the pencils of rays, which diverge from all points of an object, be again respectively collected at the same distances, they then form a new visible object equal to that from whence

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* Viner's Plan of a Course of Lectures, p. 87.

they flowed : but if the points of this new object, called the image, corresponding to those of the original object, be at a greater or less distance, they form a new *visible* object greater or less than the *original* one. Thus, therefore, we are able to form a new *visible* object, very near to us, exactly similar to an object at a great distance. I call this a *visible* object, because at the place where it is formed there is nothing to excite corresponding *tangible* ideas, as in the object from whence the rays first flowed. But in respect to our visible ideas, which we are here only considering, it is as much an object as the other ; the eye may, therefore, be so situated, in respect to this new object, that it may appear much nearer than the original object ; every object appearing greater, the nearer it is to the eye.

Now, with respect to the *brightness* of this new visible object, we are to consider that when the eye looks directly at any object, it receives no more rays from any one point, than what can directly enter the pupil : but, when an image is formed by a lens, for instance, all the rays from any one point of the object which falls upon the lens are collected together, and form a point of the image. Now if the diameter of the pupil of the eye = 0.1 inch, and the diameter of the lens be 5 inches, their areas will be as 0.01 to 25 ; or, as 1. to 2500 : there are, therefore, *cæteris paribus*, 2500 times as many rays collected to form every point of the image by the lens, as enter the eye, and form the image, supposing all the rays to be refracted. Now, although the rays diverge from every point of this image, formed by the lens, and therefore where the eye is situated it may not receive them all, yet, being situated near to it, it will receive a very considerable part, and more in proportion as it is nearer.

Hence

Hence the number of rays which the eye receives from any point of this image, may be greater than that which it receives directly from the object; and thus the image may be brighter than the object. These are some of the reasons why any distant object may be made to appear larger and brighter: and the common expression, that the object is brought nearer, is not incorrect; for the visible object is actually nearer, but not being accompanied with any tangible ideas, we call it an image of the other; whereas it is a visible object formed by the same rays as the original visible object. Looking, therefore, at the visible object thus formed, we get an idea of the original visible object, seen under the same angle; and from thence, by association, we conclude, what are the corresponding tangible ideas.

I shall conclude this Lecture on vision, with some more reflections on the eye. They are extracted from a sermon of Mr. Newlin's.

Light is truly pleasing in it's own natural simplicity, and is the ornament and glory of every other object. But the eye receives it always with a fresh and increasing pleasure, as it is varied and diversified, by putting on so many sorts of colours, like so many changes of raiment.

Every time that the eye opens and expands itself, it draws as it were the whole visible world into it's own narrow compass; and there is a new creation within itself. *The sun, that marvellous instrument of the Most High; the moon, that shineth in the firmament of heaven; the stars, that numberless host; the rainbow, that glorious circle, which is bent by the hands of the Most High; the virgin purity and unsullied whiteness of the snow; the beautiful embroidery of flowers; the rich cloathing of the meadows, and the cattle upon a thousand hills,* are presented to the eye by the LORD OUR

MAKER, and set before it, as on a spacious theatre.

The great source of light, which shews every thing to the eye, casts forth so bright and dazzling a lustre, that it would bear too hard upon it, and injure our visual faculty, if it were placed too near the sight; but it is fixed at so remote a distance from us, that we look upon it with pleasure, and enjoy it's glory.

When the eye is wearied with it's daily service, and the night spreads a veil of darkness over this lower world, the curtain that is hung before the eye falls down, and the eye-lids are shut with a close seal, till we have renewed our strength, and the morning restores the world to our view: the eye-lid not only affording refreshment and ease to the eye, but defending it from the secret perils and invisible dangers of the night.

And when day breaks, it does not shine forth at once, in full perfection, but gradually manifests itself, that the eye may not be overpowered, by a sudden issuing out, and too mighty a stream of light. The sun sends a harbinger before him, to give notice of his appearance, that the dawning of the day may prepare us to receive him.

Though every colour has a peculiar beauty, yet they are not all equally agreeable and refreshing to the eye: but the verdure of the fields is most particularly pleasing to it, and we can bear to dwell the longest upon it: God has appointed it for the common dress of nature, and made this colour the most familiar to our sight. *He leads us through the green pastures*, and adorns the herbs and plants with many varieties, even in the same colour, and changes it every day.

Time would fail me even in attempting to describe all the pleasures and advantages of sight. I cannot, however, leave the subject without one
or

or two observations. The eyes are a faithful guard to the whole man, and are placed as in a friendly watch-tower, to discern his danger, and give him friendly warning, while it is yet afar off.

The eye is instrumental in promoting the happiness of conversation. It is the eye that meets our friend with joy, and kindles and imparts the heavenly flame of friendship. It is the eye that pities, and spares, and yearns over the miserable object, with generous compassion. It was with the eye that our SAVIOUR reproved St. Peter. *O Lord, how marvellous are thy works! in wisdom hast thou made them all!* The eye that sees, gives witness of thee; and the ear that hears, confirms it's testimony.

LECTURE XIX.

OF COLOURS.

NO philosophical subject is more worthy of your attention than *light*; it is the means by which all the beauties and glories of the creation are laid open to view; with some of it's curious properties you are well acquainted; a new scene will now rise before you equally admirable with those that have preceded.

I have hitherto considered light as a body uncompounded, and of parts resembling each other; but we are going to examine it's texture more closely. You will now see that this fluid, so simple in appearance, is made up of very different particles; that it is composed of very different coloured tints; and that from the nature of this composition arises that charming variety of shades which paints the face of nature.

Whatever pleasures we derive from the beauty of colouring, we owe it to the different rays of light, each object sending back to our eyes those rays, which *it's surface* is best adapted to reflect: in this sense the blushing beauties of the rose, and the modest blue of the violet, may be considered as not in the objects themselves, but in the light that adorns them. Odour, softness, and beauty of figure, are their own; but it is light which dresses them up in those robes which shame the monarch's glory.

Natural philosophers were formerly of opinion, that the solar light was simple and uniform, without any difference or variety in it's parts, and that the different colours of objects were made by refraction, reflection, or shadows. But *Newton* taught them

them the errors of their former opinions; he shewed them to dissect a single ray of light with the minutest precision, and demonstrated that every ray was itself a composition of several rays all of different colours, each of which when separate held to it's own nature, simple and unchanged by every experiment that could be tried upon it. Or to be more particular, light is not all similar and homogenous, but compounded of heterogenous and dissimilar rays, some of which in like instances being more refrangible, and others less refrangible, and those which are most refrangible are also most reflexible; and according as they differ in refrangibility and reflexibility, they are endowed with the power of exciting in us sensations of different colours.

Newton's theory of light and colours is striking and beautiful in itself, and deduced from clear and decisive experiments, and may be almost said to demonstrate clearly, 1st, That lights which differ in colour, differ also in degrees of refrangibility.

2d, That the light of the sun, notwithstanding it's uniform appearance, consists of rays differently refrangible.

3d, That those rays which are more refrangible than others, are also more reflexible.

4th, That as the rays of light differ in degrees of refrangibility and reflexibility, so they also differ in their disposition to exhibit this or that particular colour; and that colours are not qualifications of light derived from refractions or reflections of natural bodies, as was generally believed, but original and connate properties, which are different in different rays, some rays being disposed to exhibit a red colour and no other, and some a green and no other, and so of the rest of the prismatic colours.

5th, That the light of the sun consists of *violet*
A a 4 making,

making, *indigo* making, *blue* making, *green* making, *yellow* making, *orange* making, and *red* making rays, and all of these are different in their degrees of refrangibility and reflexivity; for the rays which produce red colours are the least refrangible, and those that make the violet the most; and the rest are more or less refrangible as they approach either of these extremes, in the order already mentioned: that is, orange is least refrangible next to red, yellow next to orange, and so on; so that to the same degree of refrangibility there ever belongs the same colour, and to the same colour the same degree of refrangibility.

6th, Every homogenial ray, considered apart, is refracted according to one and the same rule, so that it's sine of incidence is to it's sine of refraction in a given ratio; that is, every different coloured ray has a different ratio belonging to it.

7th, The species of colour, and degree of refrangibility and reflexivity, proper to any particular sort of rays, is not mutable by reflection or refraction from natural bodies, nor by any other cause that has been yet observed. When any one kind of rays has been separated from those of other kinds, it has obstinately retained it's colours, notwithstanding all endeavours to bring about a change.

8th, Yet seeming transmutations of colours may be made, where there is any mixture of divers sorts of rays; for, in such mixtures, the component colours appear not, but by their mutually alloying each other, constitute an intermediate colour.

9th, There are therefore two sorts of colour, the one original and simple, the other compounded of these; and all the colours in the universe are either the colours of homogenial, simple light, or compounded of these mixed together in certain proportions. The colours of simple light are, as

we observed before, violet, indigo, blue, green, yellow, orange, and red, together with an indefinite variety of intermediate gradations. The colours of compounded light are differently compounded of these simple rays, mixed in various proportions: thus a mixture of yellow-making and blue-making rays exhibit a green colour, and a mixture of red and yellow makes an orange; and in any colour the same in specie with the primary ones, may be produced by the composition of the two colours next adjacent in the series of colours generated by the prism, whereof the one is next most refrangible, and the other next least refrangible. But this is not the case with those which are situated at too great a distance; orange and indigo do not produce the intermediate green, nor scarlet and green the intermediate yellow.

10th, The most surprising and wonderful composition of light, is that of *whiteness*; there is no one sort of rays which can alone exhibit the colour, it is ever compounded, and to it's composition all the aforesaid primary colours are requisite.

11th, As *whiteness* is produced by a copious reflection of rays of all sorts of colours, when there is a due proportion in the mixture; so on the contrary, *blackness* is produced by a suffocation and absorption of the incident light, which being stopped and suppressed in the black body, is not reflected outward, but reflected and refracted within the body till it be stifled and lost.

Having thus endeavoured to give you a general idea of the theory of colours, I shall proceed to explain the subject more fully, illustrating it by the experiments so admirably devised by Newton. The sun shines favourably for our purpose, we will therefore go into the dark room; I have been,
you

you see, particularly careful to exclude all light from the room, but what enters through the tube I have fixed in the window-shutters. I admit a beam of light through a hole in this tube of about $\frac{1}{4}$ of an inch diameter, the beam darts through the hole, and forms on the floor an image of the sun nearly circular. I now place my glass prism so as to receive the beam of light, and you observe how beautifully that beam is refracted into different coloured rays. The cylindric beam of light passes into the prism, is there dilated, and by refraction thrown into an oblong form, exhibiting on the opposite side of the room an amazing spectrum of colours. The prism is triangular at each end, about 6 inches long, and is polished on the three sides. I have placed it parallel to the horizon, with its axis perpendicular to the beam of light. On turning the prism slowly about its axis, you see that the refracted light on the wall, or the coloured image of the sun, first descends, and then ascends; between the ascent and descent, that is, where the image is stationary, the prism is to be fixed, because in that situation the refractions of the light on the two sides are equal to one another.

Whenever you would have the refractions on both sides of the prism to be equal, you must note the place on the wall where the image stands still, or the mean point between two contrary motions, and there fix the prism. I shall make all the following experiments with the prism in this situation, unless some other position be mentioned.

The refracted light falls perpendicularly upon a sheet of white paper, placed on the opposite wall of the chamber, where an oblong (not an oval) image of the solar spot is formed; it is terminated by two rectilineal and parallel sides, and two semicircular ends; the sides are better defined than the

the ends, which are confused and indistinct, because the light at the ends decays and vanishes by degrees.

The lower extremity is *red*, above this is placed the *orange*, afterwards the *yellow*, then the *green*, the *blue*, the *indigo*, and lastly the *violet*, which is placed in the upper part of the image. There are, you see, innumerable gradations connecting and uniting the primary ones, each colour gradually degenerating as it were into the succeeding one. You will not always be able to distinguish clearly the whole seven colours, as it requires a very excellent prism, and great attention and accuracy in performing the experiment, to prevent some of those which most nearly resemble each other, from being confounded together: you will, however, scarce ever fail in seeing five distinctly marked, the lower red gradually declining into a yellow, the yellow succeeded by an intense green, above this a bright and lovely blue, and then a soft but glorious mazarine or violet colour.

The breadth of the spectrum answers to the breadth of the sun's circular image. If the prism had a smaller angle, the length of the image would be less. If I turn the prism so that the rays emerge more obliquely, the image soon becomes an inch or two longer; but if I turn it about the contrary way, so as to make the rays fall more obliquely on the side nearest the hole, it soon becomes an inch or two shorter: therefore in repeating this experiment, you should be careful so to place the prism that the refraction on both sides may be alike.

This experiment is represented *fig. 9, pl. 6*. T the tube through which the beam of light enters the room, proceeding in the direction T to I, but is turned out of this direction by a prism SPD, whose axis is perpendicular to the beam; by this the rays of light are refracted so as to form a coloured

loured spectrum MN upon the screen KL . The most refrangible rays being thrown to M furthest from I , but the least refrangible being turned less out of their course, fall upon a part of the screen N , and nearest I , while those that are refrangible in the intermediate degrees will fall between M and N , forming, instead of a circular space, a long spectrum bounded by right lined sides and circular ends, and whose length is at right angles to the direction of the axis of the prism.

The size of the hole in the window-shutter, the different thickness of the prism through which the rays pass, the different inclinations of the prism to the horizon, and the various altitudes of the sun, make no sensible change in the length of the image, nor is it affected by the different matter of which the prism is formed. With a prism, whose refracting angle is $62\frac{1}{2}$ at $18\frac{1}{2}$ feet from the prism, the length of the image is about $9\frac{3}{4}$ or 10 inches.*

If the rays were equally refrangible, that is, equally inclined to the surface of the prism in the ingress and egress, their direction would be only changed; the image would be a circle, which will appear sufficiently clear by your considering these diagrams. Let ABC , fig. 8, pl. 6, be a section of a triangular prism at right angles to its axis. Suppose JN to be a ray incident at N , and thence refracted at E on the surface CB , where it is again refracted into the situation EM . Let in be another ray, parallel to the former, and consequently incident at n with the same angle.

Now if the ray in have exactly the same capability or disposition to be refracted by the prism, as the ray JN , the angles of refraction will be also equal,

* As the light of the sun is not always to be obtained, I have prepared a small model with coloured silk strings, to shew the nature and proportion of the coloured rays issuing from a prism.

equal, and in will, when refracted into the directions ne and me , still continue parallel to the ray JN , which is refracted into NE and EM .

But if it be more refrangible, it will be refracted into other directions, as nf , and fg , verging more towards the base AC ; or if it be less refrangible, it will be refracted into directions, as nh , and hk , that verge less towards the base AC .

Whence it appears, that if a collection or pencil of rays fall parallel to each other on one of the sides of a prism, and do not proceed parallel to each other on their emergence, it must be because some of the rays are more refrangible than others.

The preceding experiment therefore with the prism proves, *that the sun's light is composed of rays whose refrangibilities are not all the same*; for after emerging from the prism, instead of illuminating a circular space, they are spread into a long spectrum, bounded by right-lined sides, and circular ends, and whose length is at right angles to the axis of the prism.

Turn the prism, which is so placed that the axis is perpendicular to the beam of light, that the image may be stationary, and there fix it; this being done, look through the prism at the hole, the length of the image will appear to be many times greater than the breadth; the most refracted part being violet, and the least refracted red; the middle parts blue, green, yellow, in order.

Now remove the prism out of the sun-beam, and look through it at the hole, and you will have the same appearance; if all the rays were equally refracted, the hole would appear round when refracted through the prism. This therefore, like the preceding experiment, proves that at equal incidences there is a considerable inequality of refraction.

refraction. Besides the different refrangibility, the foregoing experiments shew also another remarkable difference between the rays; namely, *that the different refrangibility of the rays is joined with a difference in colour; and all the rays, as they are more or less bent by refraction, have a colour peculiar to themselves.*

To render this subject clearer, and to shew that these appearances are not accidental, but inherent properties of light, Sir I. Newton tried what would be the effect of refracting the rays of light a second time: for this purpose he let the light refracted by the first prism fall upon a second prism, placed at about one foot from the first: the first prism was in an horizontal, the second in a vertical situation. An image was formed by the second prism, similar both in the arrangement of colours, and it's dimensions to that in the first experiment, with this only difference, that it was not now in a vertical, but in an inclined position. Now if the effects were only caused by a modification of light produced by the prism, the second ought to form in breadth the image that the former made in length, and thus produce a square spectrum, which is contrary to the fact. The inclination of the spectrum is solely occasioned by the unequal refrangibility; those rays that were most bent by the first prism, being also by the second; the upper part in both prisms suffering a greater refraction, and the lower part a less refraction; likewise, as before, the upper part appears violet, and the lower part red.

At *fig. 10, pl. 6*, is a diagram to illustrate this experiment. A B represents the second prism in a vertical direction, that it may again refract the rays which come from the first. By the first prism the rays are refracted upwards, by the second sideways; by the first it is refracted to *m n*, while

while MN is the image formed by the refraction of the two cross prisms. The breadth of the image is not increased, the upper part suffers a greater refraction, and the lower a less one in both prisms.

If a third, and even a fourth prism, be placed in the same manner after the second, the result will be the same; and the most refrangible rays will still be most refracted, and the least the least refracted, whilst their colours remain unchanged.

Let us now proceed to another experiment. Here, as in the first, the light is transmitted through a prism, but the coloured image is received on a screen which I have placed in the middle of the room; there is a hole in the screen, through which the rays of any single colour may be suffered to pass alone, by raising or lowering the screen. Thus for instance, I place the hole against the blue part of the image, so that none but the blue rays go through it; these are again refracted by a prism: now you see that the blue rays, after having passed through the prism, continue the same as before, without any manner of alteration, forming a blue image on the opposite side of the wall, and the figure of this image is circular. The direction of the beam is altered, but the rays are not *dilated or separated into different sorts*, as the common beam of light was by the first prism. I now move the screen to the yellow rays, and you observe that these rays falling on the second prism are refracted to the side of the room, and there form only a yellow spot, and the same with the rest of the colours; so that none of these colours are changed by refraction. Further, if you place any small bodies in these circular images, they will appear of the same colour with the image, red in the red light, green in the green light, &c. so that the colours are no ways changed by reflection. Again, if you look

look at any of these spots through a prism, they still preserve their colour, and are not expanded or dilated in length; so that *homogenial* light suffers no manner of alteration in any case.

In all the trials that have been made, it appears, that those rays which are most refracted at first, are always most refracted; and those that are least at first, are always least afterwards. It is therefore plain, *that every ray of light has a peculiar degree of refrangibility, which cannot be changed by any reflections or refractions, but remains constantly and invariably the same.*

The different refrangibility of the rays of light is a cause of confusion in bodies seen through a refracting medium; for this will occasion the different rays flowing from the same point, to be refracted to different points on the retina. Thus, small objects, placed in a sun-beam, and viewed through a prism, will be seen but confusedly; but if they are placed in a beam of homogeneous light, separated by a prism, they will appear as distinct through a prism as when viewed by the naked eye.

As the light reflected from all terrestrial bodies is the solar light, we may fairly conclude from the foregoing experiments, that *the light reflected or emitted from all bodies, consists of rays differently refrangible*: and this may be further proved, for if you look at any object through a prism, that object will appear tinged with colours. Take a small part of a body, illuminate it strongly, and look at it through a prism, and you will have an oblong image with all the colours; a star, a lamp, a candle, a burning coal, a red-hot iron, or any burning matter seen through a prism, will present you with the same appearances.

If you are desirous of seeing a complete specimen of *analytical* reasoning, you should read SIR
I. NEWTON'S

I. NEWTON'S OPTICS, where you will find him pursuing this subject in a variety of ways; putting nature to a thousand proofs, in order to establish his deductions on a sure foundation. It is impossible for me to give you even an imperfect idea of this method, in these Lectures; it will be sufficient if you here attain so much knowledge as will awaken your attention to a fuller and closer investigation of the subject. Having shewn you by the preceding experiments, that *the light of the sun consists of rays differently refrangible*, I shall now endeavour to prove to you, that *the rays of light, which differ in colour, differ also in refrangibility*.

It is not indeed always necessary that judgment should be founded on *demonstration*, in order to obtain your confidence, for demonstration is rarely to be found. It is expedient, therefore, to study the art of judging accurately upon *probabilities*, which, where they can be clearly discerned, are a sufficient ground for confidence, until new light break in, or circumstances change, whereon a new judgment may be formed with similar accuracy. It is the vain expectation of *absolute certainty* that keeps many continually wavering and irresolute; for being afraid of trusting to any thing that has not such certainty, and being able to find it no where, they live in a round of doubts, without being able to settle on any one point. You may be assured that some courage, as well as caution, is requisite, either to secure freedom of thought, or open a passage to proficiency in any science.

Here is an oblong piece of paper, one half of which is coloured strongly with red, the other with blue; place it upon this piece of black cloth near the window, where it will be strongly illuminated; now look at it through a glass prism, held parallel to it, and to the horizon, with the refracting angle upwards, the paper will appear broken.

and divided into two parts, the blue half is lifted higher by refraction than the red. If you turn the refracting angle of the prism downwards, so that the paper may be carried lower by refraction, the blue half will be carried lower than the red half. This experiment shews clearly, that the light from the blue *is more refracted, and is therefore more refrangible, than the light from the red.*

I shall now wrap a thread of black silk several times round a piece of paper, one half of which is coloured like that we used in the preceding experiment, and the thread appears as if it were so many black lines drawn upon the colours. Darken the room, and set the paper up perpendicularly against the wall, so that one of the colours may stand to the right, the other to the left; now illuminate it strongly with a candle, while with a lens of a long focus, I collect the rays, so as to form an image of the coloured paper upon the white screen, the screen being at about the same distance from the lens as the lens is from the coloured paper.

Move the screen backwards and forwards to find where the images of the blue and red parts of the paper are most distinct; this is easily known by the images of the black threads of silk, and you will find that where the red half appears distinct, the blue half is confused; and on the contrary, when the blue half appears distinct, the red is so confused that the black lines are scarcely visible: the space between these two situations of the paper is about $1\frac{1}{2}$ inch, the distance of the paper from the lens being about 6 feet. The focal distance of the red rays being *longer* than that of the blue, is a proof that the blue rays are more refrangible than the red; and we obtain a new demonstration of the difference in the refrangibility from the different focal distances, at which the rays proceed from different colours; for those whose rays are most refrangible
must

must be collected and united at the shortest distance. Therefore rays that differ in their colour differ also in their degrees of refrangibility.

The different refrangibility of the rays of light is a great obstacle to the perfection of telescopes and microscopes. This is a clear inference from our last experiment, for no rays issuing from a point can be refracted by a lens to a single point.

From what has been said it is also plain, that if the solar light consisted but of one kind of rays, there would be but one colour in the world; or, in other words, all things would be of the same colour.

From one experiment to another, Sir I. Newton was led to what he justly calls the *experimentum crucis*, which I shall relate to you so as to enable you to repeat it at your leisure, as we have already employed as much of our time as can be well spared on this subject. He took two thin boards, and placed one of them close behind the prism at the window, in such a manner that the middle of the refracted light might pass through the hole made in it, and the rest be intercepted by the board, and be refracted on the other board which he placed at about the distance of 12 feet; having made a small hole in the second board also, and placed it in such manner that the middle of the refracted light, which came through the hole in the first, might pass through that of the second, the rest being intercepted by the board might paint upon it the coloured spectrum of the sun.

He then placed another prism behind the second board, so that the light which was transmitted through both the boards might pass through that also, and be again refracted before it arrived at the wall.

This being done, he took the first prism in his hand, and turned it about it's axis, so as to make the several parts of the image cast on the second

board successively to pass through the hole therein, and fall upon the prism behind it, that *he might observe to what places on the wall* they would be refracted by the second prism; and it appeared, that the light which was most refracted by the first prism was also most refracted by the second, and went to the higher part of the wall; and the light which was least refracted by the first, was also least refracted by the second; and that the most refrangible was violet, and the least so red. During the experiment the two boards and the second prism remained unmoved, by which means the incidence thereon was always the same; so that without any difference in the medium some of them shall be more refracted than others; and that according to their different degrees of refrangibility they will be transmitted through the prism to different parts of the wall.

Fig. 11, pl. 6. V S T is the prism that first receives the solar light; this is refracted and falls upon the middle of the board P X Q, the middle part of which falls upon the second board p x q. By turning the prism V S T slowly to and fro about its axis, the image will be made to move up and down, so that all the parts from one end to the other may be made to pass successively through the hole g. a s t another prism to refract the light passing through the hole g on the screen Y Z y. The position of the holes remaining constantly the same, the incidence of the rays on the second prism was the same in all cases; yet with that common incidence some rays are more refracted, and others less.

The rays of light that fall on a reflecting surface in the same angle, if reflected at all, are reflected in the same angles; consequently there will be no such separation in degree of the rays of light by reflection as there is by refraction. This position is readily proved.

proved. I shall place this plane mirror in an horizontal position, so as to receive this beam from the hole in the window-shutter, and it is thereby, you see, reflected to the opposite wall; the figure of the reflected light is circular like the hole, but there is no separation of the rays as in refraction, nor any colours produced by reflection; the rays, which have the same incidence, running parallel to one another after reflection, being reflected at equal angles: though the most refrangible will be the soonest reflected, if they move out of a dense into a rare medium; a circumstance which does not in the least affect the present proposition.

The rays of the sun's light, however, which are refrangible, are also more reflexible than others. *KLI, fig. 12, pl. 6*, represents a prism; the angle *K* is a right angle; the other angles *L, I*, are equal to each other; *TM* a beam of light that passes through the surface *KI*, and is incident at *N* upon *LI*. It will emerge in the direction *MS*; but when the angle of incidence at *M* is such that the sine of the angle of refraction is equal to the radius, the angle of refraction becoming a right one, the ray cannot emerge, but will be totally reflected.

By turning the prism slowly about its axis until all the light which went through one of its angles, and was refracted by it, began to be reflected by its base, Sir I. Newton found, that those rays which had suffered the greatest refraction were sooner reflected than the rest; he therefore conceived that those rays of reflected light, which were most refrangible, did first of all, by a total reflection, become more copious in that light than the rest; and that afterwards the rest also, by a total reflection, became as copious as these. To try this, he made the reflected ray, *fig. 12, pl. 6*, pass through another prism *TVX*, so placed as to se-

parate it's component colours by refraction ; O M, the reflected beam, then the light, which first begins to be reflected, consisting almost entirely of violet light, were by the second prism so refracted as to fall on q, and paint a violet colour. As the first prism continues to be turned on it's axis, the light is more and more copiously reflected, and the colours between q and r appear in succession till the red appears, when the reflection becoming total, the colours formed by refraction at Q R S disappear, as those at q s appear.

In the beginning of this Lecture I observed to you, that no *one* kind of rays would exhibit whiteness ; it is the most surprising and wonderful composition, an assemblage of all the colours of the prism in union. *Whiteness, or the solar light, is always compounded ; and all the primary colours mixed in due proportion, are requisite to it's formation.* I shall illustrate this by one of the most celebrated, and most simple of Sir I. Newton's experiments.

I darken again our room, and, as in the first experiment, refract a beam of light by a prism, and receive it's image on the screen. Let us remove the screen, and hold this lens, so that the refracted rays may fall upon it ; this you perceive has occasioned the coloured light, which diverged from the prism, to unite and meet again at it's focus ; and you have upon a piece of paper held behind the solar image intensely coloured : the rays have no sooner, you see, passed through the lens, than they begin to mix and efface each other, and lose the fine harmonious proportion that was before exhibited in the spaces of the coloured image. As you remove the paper from the lens, the colours will approach more and more to each other, and by mixing together will be more and more diluted. You are now at the focus, and, you see, they are perfectly mixed

mixed together, the colours wholly vanish, and are converted into whiteness, they forming a small circular image totally white; the red no longer displays it's lively flame, the green boasts no more the livery of the spring, nor the blue the lucid robe of heaven, but all blended together exhibit the whiteness of the sun, from whence they proceeded. Remove the paper still further back, so as to receive the rays after having crossed at the focus, and as they diverge you see they again renew their splendor and colour, but in a contrary order, the red being now above, and the violet below. This re-appearance of the colours beyond the place where they were blended, is a further proof of the immutability of the primary colours, as it shews that they neither lose their colour or quality by being blended or intersecting each other, and that the *whiteness* which appears is produced only by their *mixture*.

The whiteness is made up of all the colours of the image, for if any of the rays be intercepted in their passage, the whiteness ceases, and degenerates into that colour which arises from the composition of those which were not intercepted, but suffered to pass through the lens; and if the intercepted colour be again let pass, and fall upon the compound, it will immediately restore it's whiteness.

That in forming the white the rays do not suffer change by acting on each other, is clear; for if you hold the paper beyond the focus of the lens, and stop the red colour, the violet suffers no change; nor will the red be changed by stopping the red, and letting the violet pass.

When the paper is held at the focus, if you look through a prism at the white circular image, you will have a coloured spectrum; let any ray be intercepted while the image is thus examined, and

then let it pass again, and the colour will appear and disappear as often as you repeat the experiment, the remaining colours not suffering any change; clearly shewing, that one colour depends on one kind of rays, and another colour on another kind. So replete and decisive are the experiments of Sir I. NEWTON, that they not only prove the proposition they were primarily invented to illustrate, but at the same time they also strengthen the truth of other propositions.

Convincing as were these experiments, the fertile imagination of NEWTON invented new ones, which, though different from each other, all concurred to prove the same thing; they seemed to rise under his hands, as the poets make flowers spring under the feet of their beauties.* He caused an instrument to be made in form of a comb, with teeth $1\frac{1}{2}$ inch broad, and at two inches distance from each other; by passing this comb over the lens placed as in the last experiment, part of the colours were intercepted by the teeth, while the rest proceeded on to the paper placed at the focus of the lens. This image appeared white when the comb was taken away, but when this was interposed the whiteness was changed into the colour passing through the comb. When the motion of the comb is slow, the colours red, yellow, green, blue, purple, always succeed one another; but when the comb is moved quickly, the colours following one another with extreme rapidity, cannot be distinguished, and from the confusion of the whole there arises one uniform colour; the impression of all the colours is at once in the same part of the eye, and they jointly excite the sensation of whiteness.

Here is a top, such as we were used to spin in
our

* Algarotti's Philosophy of Newton explained,

our younger days ; the surface is divided into certain proportions, to accord with the coloured spectrum of the prism : by pulling this string I shall make the top revolve rapidly on it's axis ; while it is so revolving you can distinguish none of the colours singly, but the whole appears white, and this whiteness will be greater in proportion as the particular colours are brighter.

The colours produced by the prism are not only the most beautiful in nature, but each in itself continues separate and unalterable. When one of these primitive rays has been separated from the rest, nothing can change it's colour ; send it through other prisms, refract or reflect it, still it remains unalterable, the red ray preserves it's crimson, and the violet it's purple beauty. *Whatever object falls under any of them soon gives up it's own colour, though ever so vivid, to assume the homogenous light of the prismatic ray.* Take a bit of paper, and place it in the red-making ray, and it will appear red ; place it in the other coloured rays, and you will always find it assume the radial colour. Take a piece of coloured paper, and put it in the red light, and it will appear red ; hold it in the yellow, orange, &c. and it will appear orange, yellow, &c. respectively. In short, no art can alter the colour of a separated ray ; it gives it's tint to every object, but will assume none from any ; neither reflection, refraction, nor any other means, can make it forego it's native hue ; like gold, it may be tried by every experiment, but will still come forth the same.

It will be necessary here to explain the method used by Sir I. Newton, to define the boundaries of each colour in the prismatic spectrum. You observed in the image, that though there was a manifest difference of colour not only between the two extremes, but also in the intermediate parts,

parts, yet the exact place at which any one colour ended and another began was far from being sufficiently distinguishable; this indistinctness was occasioned by rays of every kind, proceeding from all parts of the sun's disk; an entire image of the sun is projected on the paper, consisting of a circle of each particular colour; and as the rays differ in kind by infinitesimal degrees, from the extreme red to the extreme violet, there must, in fact, be thousands of these circles in the oblong image, the centers of which are infinitely near to each other, so that the light is intimately mixed, especially in the middle of the image, where it is brightest.

He therefore considered, that if these circles could be made less, while their centers kept the same distances and positions, their interference and mixture with each other would be proportionably diminished, and that they would be so diminished, if without the room at a great distance from the prism towards the sun, an opaque body was interposed, having a round hole in the middle of it, to intercept all the sun's light, except as much as coming from the middle of it's disk could pass through that hole to the prism; for then the separate circles would no longer answer to the whole disk of the sun, but only to that part of it which can be seen from the prism through that hole. But to make these circles answer more distinctly to the hole, a lens is to be placed by the prism, to cast the image of the hole, that is, of each separate circle distinctly on the paper.

At about 10 or 12 feet from the window Sir I. Newton placed a lens, by which the image of the hole might be distinctly cast upon a sheet of paper at 6, 8, 10, or 12 feet from the lens. Immediately after the lens he placed a prism, by which the refracted light might be thrown upwards or sideways; moving the paper that received the image nearer

nearer to or further from the prism, till he found the situation, where the sides of the image were, most distinct.

Fig. 13, pl. 6. F is the hole in the window-shutter; MN a lens whereby the image of that hole is cast distinctly on the paper at I; ABC a prism to refract the rays, emerging from the lens to another paper at pt; the round image at I is thereby turned into an oblong image pt falling on the other paper. This image pt consists of circles placed one after another in rectilinear order, the circles are equal in magnitude to the circle I; consequently by diminishing the hole F, they may be at pleasure diminished, whilst their centers remain in their places. By this means the breadth of the image pt may be made forty times, and sometimes sixty or seventy times less than it's length, and thereby the mixture of the rays as much or as little as you please.

By this means he obtained a distinct termination of the images of the hole without any penumbra, and therefore only extending the least degree into each other, and consequently there was very little mixture of heterogenial rays. By enlarging or diminishing the hole in the window-shutter, he made the circular images greater or less at pleasure, and thereby the mixture of rays in the oblong image was as much or as little as he chose; sometimes making the image 40 times, and sometimes 60 or 70 times less than it's length.

Thus the light was rendered sufficiently simple for trying any of his experiments about homogenous light, the heterogeneous rays being so few as hardly to be perceived, excepting in the indigo and violet, which being dark colours easily suffer an allay, even by the little scattering light refracted irregularly by the inequalities of the prism.

When

When he had thus got the sides of the coloured image distinctly defined, he delineated the outlines of it on paper, holding the paper so that the image might fall on the paper, and coincide with it exactly; while an assistant marked the confines of each colour, by lines drawn across the image. This was frequently repeated, both on the same and different papers; the observations were found to agree well enough with each other, and the sides were divided like a musical chord, and were in proportion to one another, as the numbers 1, $\frac{8}{9}$, $\frac{5}{6}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{1}{2}$, $\frac{3}{16}$, and $\frac{1}{2}$, and so represented the chords of the key, and of a tone, a third minor, a fourth, a fifth, a sixth major, a seventh, and an eighth above that key.

The length of the spaces, which the 7 primary colours possess in the spectrum, exactly corresponds to those of the chords that sound the seven notes in the diatonic scale of music.

From this reasoning, colours and sounds have been thought to be, in some respect, similar. There are 7 notes in music; there are also so many primary colours: the distance between each note is ascertained; a similar distance is also found between each coloured ray. But the diversities between them are more numerous than the similitudes. The combination of tones increases their beauty; but the combination of colours deadens their effect. The succession of sounds have a wonderful influence on the mind; the succession of colours has scarce any. Notwithstanding this, Pere Castel has written a treatise, to prove that as the *ear* finds pleasure in the succession of sounds; so the *eye* may have a similar one from the succession of colours. For this purpose, he constructed an *ocular harpsichord*, which, instead of sounding to the ear, presented colours to the eye: the prismatic rays furnished the notes, and the

the shades between were substituted for the semitones. Sounds furnish the ear with all its pleasures, but colours furnish the eye but with half its pleasure; therefore, little is to be expected from the music of colours. To make such an instrument satisfy the sense of sight, the beauty of figure must be united to that of colour.

The foregoing principles account for several phenomena, that were inexplicable before Sir Isaac Newton had investigated the theory of colours. Among others, why, upon looking at any object through a prism, the edges only appear tinged with colours, and that in a certain order. Thus, when you look through a prism, at any object, (if not too small (particularly if it be white), the edges only of the object are coloured; one edge red, orange, and yellow; the other blue, indigo, and violet. These colours are the extremities of so many images of the object, as there are rays of light differently refrangible. This will be best explained by a diagram. Let *ABCD* *fig. 17, pl. 6*, be a white figure, viewed through a prism *HIK*; *CE, DE*, are rays proceeding from the extremities, which, if the prism were not interposed, would meet at *E*; but by means of the prism, are unequally refracted; the red uniting in *G*, the violet at *F*; the intermediate one between *G* and *F*, into as many points as there are rays differently refrangible. The eye being situated so as to receive these rays, sees, in this refracted direction, the image *aosp* augmented in height, by the quantity *bo*, which is that of the rays, separated by refraction. The edges of this image are coloured; the lower edge red, from *a* to *e*; orange, from *c* to *d*; and yellow, between *d* and *e*. At the upper edge, blue, from *l* to *m*; indigo, from *m* to *n*; violet, from *n* to *o*. From what we have said, it is easy for you to perceive, that these colours are

the extremities of so many images of the object; each colour occupying a space, equal in extent to that of the card A B C D, which receives the light of the sun, which light is composed of all the rays. The red image, therefore, extends from a to b; the orange, from c to i; the yellow, from d to k; the green, from a to l; the blue, from f to m; the indigo, from g to n; the violet, from h to o.

This explains clearly, why the extremities only are coloured, while the middle remains white; the colours anticipate one on the other, so that they are all mixed together in the space between h and b; in the small intervals between e and h, and b and l, it is nearly white. It is only from a to e, and from l to o, that the colours are sufficiently pure and unmixed, to be apparent.

If the object you look at through the prism is small, and viewed at a distance, the whole surface is coloured; for when the object is small, each object occupies less space; whilst the quantity that the rays are separated from each other, is the same, they are consequently less mixed, and more apparent.

If a black object be surrounded with a white one, the colours which are perceived, are to be derived from the light of the illuminated object spreading into the regions of the black; and therefore they appear in a contrary order to what they do when a white object is surrounded with a black one.

It is the same when an object is viewed, the parts of which are less luminous than others; for, in the borders of the more and less luminous parts, colours ought always to arise from the same principle, viz. from the excess of light of the more luminous object, and to be of the same kind as
if

If the darker parts were black, but yet to be more faint and dilute.

What is said of colours made by prisms, may be easily applied to the colours made by the glasses of telescopes and microscopes, or by the humours of the eye; for if the object-glass of a telescope be thicker on one side than the other, or if one half of the glass, or one half of the pupil of the eye, be covered with any opaque substance, the object-glass, or that part of it or of the eye which is not covered, may be considered as a wedge with crooked sides: and every other pellucid substance has the effect of a prism, in refracting the light that passes through it's substance.

Though the foregoing theory of light and colour was first fully and clearly investigated by Sir Isaac Newton, yet some traces thereof are to be found among the ancients.

Plato does not seem to have been altogether ignorant of the Newtonian system of colours; for he calls them the effect of light transmitted from bodies, the particles of which were adapted to the organs of sight. Now this is precisely the same with what Sir Isaac teaches, "that the different sensations of each particular colour are excited in us by the difference of size in those small particles of light which form the several rays; those small particles of light occasioning different images of colour, as the vibration is more or less lively with which they strike our senses." *Plato* hath gone further: he has entered into a detail of the composition of colours, and inquired into *the visible effects that must arise from a mixture of the different rays of which light itself is composed*. He thought certain rules might be laid down on this subject, if, in following and imitating nature, we could arrive at the art of forming a diversity of colours by the combined intermixture

mixture of others; adding afterwards what may be considered as the noblest eulogium ever made on Sir *Isaac Newton*. *Should ever any one*, exclaims this sublime philosopher of antiquity, *attempt, by curious research, to account for this admirable mechanism, he will, in doing so, but manifest how entirely ignorant he is of the difference between divine and human power.* It is true, God can intermingle those things one with another, and then sever them at his pleasure; because he is, at the same time, all knowing and all powerful: but there is no man now exists, nor ever will, perhaps, who shall ever be able to accomplish things so very difficult. What an eulogium are these words, in the mouth of such a philosopher as *Plato*, and how glorious is *He* who hath successfully accomplished what appeared impracticable to that prince of philosophers! And what elevation of genius, what piercing penetration into the most intimate secrets of nature, displays itself even in the passages recited from *Plato*, when we consider that philosophy was then but in it's infancy.

LECTURE

LECTURE XX.

OF THE RAINBOW.

WHEN we look back upon the knowledge of the several periods of time with which history has lent us any acquaintance, and compare it with the present, reviewing at the same time the improvements of the two last centuries, and comparing them with the whole series of what preceded, we can scarce avoid regarding the later period with a respect that approaches to veneration.

It is not to be doubted but that men have at all times the same natural abilities. That many of the sages of antiquity were men of the greatest ability, and most extensive genius, they have left sufficient evidence in the records of their works. The glory of the present period is, that genius and application have been directed into a proper course, that men have studied *things* instead of *words*, and have built their systems upon facts, not like their predecessors on theories.

I would not be understood as desirous of taking from the venerable fathers of erudition, all claim to useful discoveries; for their writings give us testimony of inventions which the most enterprising geniuses of these ages have found it impossible to equal; but these are few. With us knowledge is the offspring of experiment, and we advance nothing as a principle, but what is in a degree demonstrable, and what can be in some way put to the test of experience. On this stable foundation science has risen to its present height, a

situation in which the most sanguine of the writers in the obscurer ages could never have expected to see it ; and yet far below that degree of perfection to which I think it possible it may arrive, and to which by these very means it may be carried. It is not easy to say what will be the triumphs of modern application joined to modern genius, nor to say where it will stop, while there is the same ardour in the pursuit, the same principles to work upon, and an infinite number of facts ascertained.

The colours of the *rainbow*, which struck antiquity with amazement, no longer now create the philosopher's surprise. To Pliny and Plutarch it appeared as an object which we might admire, but could never explain. Kepler seems to have been the first who supposed that it might arise from the refraction of the sun's rays upon entering the rain drops. Antonio de Dominis enlarged a theory just hinted at by Kepler. Each succeeding philosopher went on in improving a theory, the truth of which seemed to carry great probability ; but as they were ignorant of the true causes of colour, they left the task unfinished for NEWTON to complete. You will find that the theory of the rainbow, as explained by him, is full, clear, and will impress your mind with perfect conviction.

Of the various meteors the *rainbow* is one of the most pleasing ; it's colours not only delight the eye with the mildness of their lustre, but encourage the spectator with the prospect of succeeding serenity. It is almost needless to describe this meteor, as there are very few but must have surveyed it with pleasure and surprise. You know that it is only seen when the spectator turns his back to the sun, and when it rains on the opposite side. It's colours, beginning from the under part, are violet, indigo, blue, green, yellow, orange, red, so that it contains all the beautiful and simple shades of

of the prism ; without the first, there is often an external rainbow, whose colours are less vivid and ranged in an opposite order, beginning from the under part, red, orange, yellow, green, blue, indigo, violet. Sometimes we see half, sometimes an whole bow ; frequently one, very often two, nay three have been seen. Though the rainbow is generally formed by the reflection of the rays of the sun's light, from the drops of falling rain, it frequently appears among the waves of the sea, whose heads or tops are blown by the wind into small drops ; it is also sometimes to be seen on the ground, when the sun shines on a very thick dew. Cascades and fountains, whose waters in their fall are divided into drops, will exhibit rainbows to a spectator, properly situated, during the time of the sun's shining. This appearance is also seen by moon-light, though seldom vivid enough to render the colours distinguishable ; and an artificial rainbow may even be produced by candle-light on the water, which is ejected by a small fountain, or jet d'eau. All these are of the same nature, and dependent on the same causes, some idea of which may be formed by considering these diagrams.

Let the circle *St D*, *fig. 12*, *pl. 7*, and *G ds*, *fig. 13*, *pl. 7*, represent two drops of water ; *S s*, *fig. 12*, a ray of light falling obliquely on the drop of water at *s*, instead of continuing in it's direction towards *F*, is refracted to *t*, whence it will be in part reflected to *e*, making the angle of incidence equal to the angle of reflection, where, instead of going on directly to *f*, it will be again refracted by passing obliquely out of the water into the air.

But as this ray of light consists of a pencil of rays, some of which are more refrangible than the others, the violet which is most so will proceed towards *B*, and the red, which is the least, towards *O*. If then the eye of the spectator be so placed at *O*, that

the ray of light falling upon it from the drop of water has been once reflected and twice refracted, so that eo shall make with the solar ray's S an angle SFO of $42^{\circ} 2'$; he will see the red ray in the direction or ; for it has been found by computation, that the greatest angle, under which the most refrangible rays, after one reflection, can come to the eye of a spectator, is $40^{\circ} 17'$; and that the greatest angle under which the least refrangible rays come to the eye is $42^{\circ} 2'$.

If the eye be afterwards raised to B , so that the ray eb forms with the solar ray only an angle of $40^{\circ} 17'$, he will see the violet ray in the direction bB , and the intermediate colours at intermediate directions. The same thing takes place if the eye of the spectator remaining in the same space O , the drop of water descends from D to E ; or if you suppose this space filled with drops of water, you will then see at the same time all the prismatic colours. The rays which have the intermediate degrees of refrangibility will come most copiously from drops between D and E , and exhibit the intermediate colours in the order which their degree of refrangibility requires.

Now what has been said of one globe or drop of water, is true of millions of drops. Let us now imagine a number of such drops of rain, placed in the circumference of a semicircle, in the center of which is the eye of the spectator, and we shall have a semicircular band, adorned with the seven primitive colours, and whose breadth will be equal to DE , that is, in proportion to the difference between the most and least refrangible rays.

To explain the exterior bow, let us suppose a ray of light Ss , *fig. 13*, from the sun falling obliquely on a drop of water represented by the circle Gds ; instead of continuing in it's original direction to a , it is refracted to d , from whence it

will

will be in part reflected to *e*; falling again on the concave surface, a part will be again reflected towards *g*, instead of *g o*, where it will pass into the air again, and be refracted a second time. This ray of light, like the preceding, will be now decomposed; the red, which is the least refrangible, will proceed to *O*, and the violet, which is the most so, to *B*. Now an eye situated at *O*, so as to receive the ray of light, which having been twice refracted and twice reflected by the drops of water, makes with the solar ray an angle *Sh O* of $50^{\circ} 55'$, will see the red in the direction *O r*; if the eye is lowered to *B*, so that the angle *Sh B* is $54^{\circ} 7'$, it will perceive the violet ray; and in proceeding from *O* to *B*, all the prismatic colours successively.

It has been found, that the smallest angle under which the least refrangible rays can come to the eye after two reflections is $50^{\circ} 7'$, and that the smallest angle under which the most refrangible can come is $54^{\circ} 7'$. Hence, if the sun were a point, the diameter of the exterior bow would be $3^{\circ} 10'$, and that of the interior bow $1^{\circ} 45'$, and the distance between them $8^{\circ} 55'$; but as his body subtends an angle of $32', 5''$, each bow will be increased by that quantity, and their reciprocal distance diminished.

The same effects would take place if the eye of the observer was fixed at *O*, and the drop of water ascended from *G* to *H*; or if you suppose this space filled up with drops of water, all the prismatic colours will be seen at the same time, the drops between *G H* striking the sense with the intermediate colours, in the order of their refrangibility. If, as in the preceding case, you imagine a series of such drops situated in the circumference of a semicircle, in whose center is the eye of the spectator, you will have a second semicircle, enriched with seven primitive colours, but in contrary order to the first bow. Thus there will be

formed two bows of colours, an interior and stronger by one reflection in the drops, and an exterior and fainter by two reflections, the light becoming fainter by every reflection : their colours will be in a contrary order to each other, the red of both bows bordering upon the space which is between the bows.

What has been here only supposed, really takes place when rain falls; so that when the rain and the sun (with regard to the spectator's horizon) are in opposite parts of the heaven, there is a sufficient number of drops in a proper situation for the emergent rays to form with the incident rays the angles necessary to produce a rainbow. Let E, F, G, H, *fig. 11, pl. 7*, represent drops of rain, on which the solar rays SE, SF, SG, SH, are incident; these rays, after having been twice refracted at E and F, and once reflected, fall upon the eye at O. The angle SEO formed by the incident ray SE, and the emergent ray EO being $40^{\circ} 17'$, the violet colour will be perceived at E; the angle SFO, formed in the same manner by the incident ray SF, and the emergent ray FO, being $42^{\circ} 2'$, the red is perceived at F; the drops of rain between T and F sending to the eye the necessary emergent ray for producing the intermediate colours.

Thus also the rays SG, SH, after two refractions and two reflections, are also directed towards the eye placed at O. The angle SGO, formed by the incident ray SG, and the emergent ray GO, being $50^{\circ} 57'$, the red is seen at G; the angle SHO, formed by the incident ray SH, and the emergent ray HO being $54^{\circ} 7'$, the violet is seen at H; the other drops of rain which are between G and H furnish the intermediate colours. The same may be said of the rest of the drops constituting the two semicircular bands A F B E, C H D G.

This may be illustrated by experiment, for if
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the rays of light fall on the surface of a glass sphere filled with water, they will be refracted to the other side, and there exhibit a coloured spot of refracted light; from this part the rays will be reflected to another part of the lower surface, and there be refracted a second time into the air, and dilated into all the different coloured rays, so that if a person's eye was placed under such a globe, he would observe all the different colours appear in that globe. For this purpose here is a globe filled with water, which I shall suspend in a sun-beam, at such a height that you may easily observe this phenomenon. You see it now receives the light on the upper part, refracts it from the lower into all it's different coloured rays, forming thereby a circle of coloured light on the floor much resembling the rainbow. Now if you place yourself in such manner, respecting the globe, that the rays of light of different colours may successively fall upon the eye, then you will see all those colours in the globe which before formed the variegated arch upon the floor.

This is a case exactly similar to the rainbow; for if this globe of water was placed in the heavens, it is evident that the sun-beams would be refracted through it as they are here.

To illustrate the nature of the second bow, we must let the sun-beam fall upon the lower part to the globe; you see plainly the coloured spot behind to which it is refracted; cast your eye on the upper part, and you perceive the point to which it is reflected, from whence it is a second time reflected to the fore part of the globe; and from thence you see it a second time refracted out of the globe into the air, and the beam thereby dissipated into all it's different coloured rays; and you see by the colours on the floor, that the several rays in the beam lie in a different order from what they did when refracted from the globe before:

and also you will perceive, that the colours of the beam are more dilute and faint than they were in the first experiment.

It was by this experiment that Antonio de Dominis undertook to explain the cause of the rainbow. Filling a glass globe with water, hung at a certain height, opposite to the sun, and standing himself with his back to the sun, and his face to the globe, he found that when this was in such a situation that a ray darting from the sun to the globe made an angle with another ray going from his eye to the globe of $42^{\circ} 3'$, he found the globe appeared red. If the position of the globe was altered, so as to make the angle between the solar and visual ray less, then the other colours of the rainbow arose from red down to violet, which appeared at an angle of $4^{\circ} 17'$.

You will now be able to account for all the phenomena of the rainbow; it appears always of the same breadth, because the degrees of refrangibility of the red and violet rays which form the extreme rays are always the same. The rainbow forms a greater or smaller portion of a circle. Our eye is a point of a cone, and the rays that proceed from it at the above-mentioned angles form the surface of the cone; the coloured circle is the base, part of which is visible, while the earth cuts off the part which lies above the horizon. The portion in view is of course greater or smaller, as the line of sight is more or less inclined to the horizon; this obliquity increases in proportion to the elevation of the sun; consequently the size of the bow diminishes as the altitude of the sun increases. To make this plainer, suppose the spectator on the top of a very high mountain, and the rain falling at some little distance from him, instead of a semicircular rainbow he would then see a complete ring of that beautiful meteor; a circle not like our common bow, cut off by the earth,
but

but complete and beautiful; and such is usually seen from the American Andes.

From hence we see why there is no rainbow, when the sun is above a certain altitude; the conical surface under which it becomes visible being below the horizon, when the altitude of the sun is more than 42 degrees; if the altitude is more than 42, but less than 54, the exterior bow may be visible, though the interior bow is invisible. Sometimes the rain does not occupy a space extensive enough to complete the bow, only a portion of an arch will in such cases be visible; and the appearance of this portion, and even the bow itself, will be various, according to the nature of the situation and the space occupied by the rain.

OF THE SEPARATION OF THE ORIGINAL RAYS OF LIGHT, BY REFLECTION OR TRANSMISSION, BUT DEPENDING ON THE THICKNESS OF THE MEDIUM UPON WHICH THEY ARE INCIDENT.

The foundation of a rational theory being laid, it next became natural to inquire by what peculiar mechanism in the structure of each particular body, it was fitted to reflect one kind of rays more than another. This Sir I. NEWTON attributes to the density of these bodies. This subject is not so clear as the preceding; the present theory suggests many doubts to every inquisitive mind, and is allowed by all to be attended with difficulties. There are no optical experiments, however, in which Sir I. NEWTON seems to have taken more pains, than those relating to the rings of colours which appear in *thin plates*, and which I am going to explain to you; in all his observations and investigations concerning them, he discovers the greatest sagacity, both as a philosopher and a mathematician.

The bubbles which children blow with a mixture

ture of soap and water, were observed by Dr. Hooke to exhibit various colours according to their thinness, and that when they have a considerable degree of thickness they appear colourless; from this the present theory has taken its rise. It is thus that things overlooked by the rest of mankind, are often the most fertile in suggesting hints to those who are habituated to reflection.

SIR I. NEWTON blew up a large bubble from a strong mixture of soap and water, and set himself attentively to consider the different changes of colour it underwent, from its enlargement to its dissolution. He in general perceived that the thinner the plate of water which composed the sides of the bubble, the more it reflected the violet colour ray; and that in proportion as the sides of the bubble were more thick and dense, the more they reflected the red: he therefore was induced to believe, that the colours of all bodies proceeded from the thickness and density of the little transparent plates of which they are composed. To bring this opinion nearer to certainty, it was necessary to measure the thickness of the plate of water which composed the bubble, but this was a matter of great difficulty, as the bubble was of itself of too transient a nature to undergo the necessary experiments.

Sir Isaac, who was ever fertile in expedients, recollected having observed, that as two prisms were compressed hard together, in order to make their sides (which happened to be a little convex) touch one another, they were both as perfectly *transparent* in the place of contact as if they had been but one piece of glass; but that round the point of contact, where the glasses were a little separated from each other, *rings of different colours* appeared.

To observe more accurately the order of the colours produced in this manner, he placed a glass lens, whose

whose convexity was very small, upon a plain glass. Now it is evident, that those would only touch at one particular point; and therefore, at all other places between the adjacent surfaces, a thin plate of air was interposed, whose thickness increased in a certain ratio, according to the distance from the point of contact.

He pressed these glasses slowly together, by which means the colours very soon emerged, and appeared distinct to a considerable distance; next to the pellucid central spot made by the contact of the glasses, succeeded blue, yellow, white, yellow and red. The blue was very little in quantity, nor could he discern any violet in it; but the yellow and red were very copious, extending about as far as the white, and four or five times as far as the blue. The next circuit immediately surrounding these consisted of violet, blue, green, yellow, and red; all these were very copious except the green, which was very little in quantity, and seemed more faint and dilute than the other colours. The third circle of colours was purple, blue, green, yellow, and red; in this the purple was more reddish than the violet in the former circuit, and the green was more conspicuous, being as bright and copious as any of the other colours, except the yellow; the red was also somewhat faded. The fourth circle consisted of green and red; the green was copious and lively, inclining on one side to blue, on the other to yellow, but there was neither violet, blue, nor yellow; and the red was very imperfect and dirty. Each outer circuit or ring was more obscure than those within, like the circular waves upon a disturbed sheet of water, till they at last ended in perfect whiteness.

As the colours were thus found to vary according to the different distances of the glass plates from each other, Sir Isaac judged that they proceeded from the different thickness of the plate

plate of air, intercepted between the glasses; and that this plate was by the mere circumstance of thinness or thickness disposed to reflect or transmit this or that particular colour; from whence he concluded, as before observed, that the colours of all natural bodies depended on their component particles. He also constructed a table, wherein the thickness of a plate, necessary to reflect any particular colour, was expressed in parts of an inch, divided into 1,000,000 parts.

The appearance of these circles, when the glasses were most compressed, so as to make the black spot appear in the center, is delineated *fig. 15, pl. 7*, where a, b, c, d, e; f, g, h, i, k; l, m, n, o, p; q, r; s, t; u, x; y, z, denote the colours reckoned in order from the center, viz. black, blue, green, yellow, red, purple, blue, green, yellow, red; green, red; greenish blue, red; greenish blue, reddish white.

I have already observed to you, that the thin plates, made use of in the former experiments, reflected some kinds of rays in particular parts, and transmitted others in the same parts. Hence the coloured rings appeared variously disposed, according as they were viewed by reflected or transmitted light; that is, according as the plates were or were not held up between the eye and the window. That you may understand this better, here is a table, on one side of which are mentioned the colours appearing on the plates by reflected light, and on the other those which were perceived when the glasses were held between the eye and the window. The center, when the glasses were in full contact, was perfectly transparent; this spot therefore, when viewed by reflected light, appeared black, because it transmitted all the rays; and for the same reason it appeared white, when viewed by transmitted light.

Colours

Colours by reflected light. | *Colours by transmitted light*

Black
 Blue
 White
 Yellow
 Red
 Violet
 Blue
 Green
 Yellow
 Red
 Purple
 Blue
 Green
 Yellow }
 Red
 Green
 Red
 Greenish-blue
 Red

White
 Yellowish Red
 Black
 Violet
 Blue
 White
 Yellow
 Red
 Violet
 Blue
 Green
 Yellow
 Red
 Bluish Green
 Red
 Bluish-green
 Red

In comparing the rings produced by transmitted with those produced by reflected light, the white was found opposed to the black, the red to the blue, the yellow to the violet, and the green to a colour composed of red and violet; in other words, the parts of the glass, that when looked at were white, appeared black on looking through the glass; and on the contrary, those which appeared black in the first instance, appeared white in the second; and so of the other colours, which you will more readily comprehend by considering this figure, where A B, C D, *fig. 17, pl. 7*, represent the glasses which touch at E; the black lines traced between them are the distances between the two surfaces, at different distances from the center, each distance answering to a coloured ring; the colours

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colours written above are those seen by reflected light; those underneath, are the colours exhibited by transmitted light. Newton has shewn, that the rays of any particular colour are disposed to be reflected, when the thickneses of the plate of air are as the numbers 1, 3, 5, 7, 9, 11, &c. and that the same rays are disposed to be transmitted at the intermediate thickneses, which are as the numbers 0, 2, 4, 6, 8, 10, &c.

The places of reflection or transmission of the several colours in a series, are so near each other, that the colours dilute each other by mixture; whence the number of series, in the open day-light, seldom exceeds 7 or 8. But if the system be viewed through a prism, by which means the rings of various colours are separated, according to their refrangibility, they may be seen on that side towards which the refraction is made, so numerous that it is impossible to count them. Or, if in a dark chamber the sun's light be separated into it's original rays, by a prism, and a ray of one uncompound colour be received upon the two glasses, the number of circles will become very numerous, and both the reflected and transmitted light will remain of the same colour as the original incident ray. This experiment shews, that in any series, the circles formed by the less refrangible rays exceed, in magnitude, those which are formed by the more refrangible; and, consequently, that in any series, the more refrangible rays are reflected at less thickneses than those which are less refrangible.

Water applied to the edges of the glass, is attracted between them; and, filling all the intercedent space, becomes a thin plate of the same dimensions as that which before was constituted of air: in this case, the circular rings grew less, and the colours were fainter, but

not varied in species. They were contracted in diameter, nearly in proportion of 7 to 8, and consequently, the intervals of the glasses, at similar circles, as caused by these two mediums, are as about 3 to 4; that is, as the sines of refraction out of water into air.

I have already mentioned to you the variety of colours produced by bubbles blown in soap-water: but, as these colours are commonly too much agitated by the external air to admit of any certain observation, it is necessary to cover the bubble with a clear glass,* in which situation you will find the following appearances: the colours emerge from the top of the bubble, and as it grows thinner, by the subsidence of the water, they dilate into rings parallel to the horizon, which descend slowly, and vanish successively, at the bottom. This emergence continues till the water at the upper part of the bubble becomes too thin to reflect the light, at which time, a circle of an intense blackness appears at the top, which slowly dilates, sometimes to three quarters of an inch in breadth, before the bubble breaks. Reckoning from the black central spot, the reflected colours are the same, in succession and quality, as those produced by the aforementioned plate of air; and the appearance of the bubble, if viewed by transmitted light, is similar to that of the plate of air, in like circumstances.

Take very thin plates of talc, or Muscovy glass, that exhibit these colours; then, by wetting the plates, the colours remain as before, but become more faint and languid, especially when wetted on the under side. So that the thickness of any plate, requisite to produce any colour, seems

* Nicholson's Introduction to Philosophy, vol. i. p. 283.

seems to depend only on the density of the plate, not on the density of the inclosing medium. But the colours are more vivid, as their densities are different.

If two pieces of plate-glass, or even common glass, be previously wiped, and then rubbed together, they will soon adhere, with a considerable degree of force, and exhibit various ranges of colours, much broader than those obtained by lenses. One of the most remarkable circumstances attending this method of making the experiment, is the facility with which the colours may be removed, or even made to disappear, by heats too low to separate the glasses. A touch of the finger immediately causes the irregular rings of colours to contract towards their center, in the part touched.

From these experiments it appears plain, that the colours of bodies depend, in some degree, upon the thickness and density of the particles that compose them.

Hence, if the density, or size of the particles, in the surface of a body, be changed, the colour is likewise changed.

When the thickness of the particles of a body is such, that one sort of light, or one sort of colour, is reflected; another light, or other colours, will be transmitted; and therefore, the body will appear of the first colour.

A certain determinate thickness seems to be necessary in a plate of water; for example, in order to reflect a particular colour, and a different thickness, to make it reflect any other colour; and, in general, that a less thickness is necessary, to reflect the most refrangible rays, as violet and indigo, than those which are least refrangible, as red and orange.

The

The particles of bodies reflect rays of one colour, and transmit those of another: and this is the ground of all their colours.

OF THE TRANSIENT STATE INTO WHICH A RAY OF LIGHT IS PUT, IN IT'S PASSAGE THROUGH ANY REFRACTING SURFACE, WHICH, IN THE PROGRESS OF THE RAY, RETURNS AT EQUAL INTERVALS; AND DISPOSES THE RAY, AT EVERY RETURN, TO BE TRANSMITTED, AND BETWEEN THE RETURNS, TO BE REFLECTED TO IT.

In order to account for the intervals of the coloured rings in these thin plates, and also all other cases of the reflection or transmission of light, Sir Isaac Newton advances an hypothesis; but, like a wise man, and cautious philosopher, he professes not to lay much stress upon it, though he seems not to entertain any suspicion of it's truth. Indeed, it seems to be a kind of fair inference from the preceding experiments.

The hypothesis is this: that every ray of light is, at it's first emission from the luminous body, put into a *transient state or constitution*, which, in it's progress, returns at equal intervals, disposing it, at every return, to be easily transmitted into any refracting surface it may meet with; whereas in the intervals between these returns, it is disposed to be easily reflected; so that, upon the arrival of a number of rays of light at the surface of every medium, those of them in which they were disposed to be transmitted easily, would pass the interval between the two mediums; and those which were in a contrary state, would be reflected; on which account, some light is generally reflected, and some transmitted, at every different surface on which it falls. Those states, into which the rays of light are put, he calls *sits of easy reflection and transmission*.

This hypothesis is not without difficulties, and must, therefore, be received with caution, as it was proposed, till it shall be either confirmed or confuted by experiment, and a new theory substituted in it's place.

When arrived, as it were, at the confines of material nature, you must expect to meet with some confusion and darkness in our explanations. There are barriers to our knowledge, which cannot be passed by any force of human faculties. Sir Isaac Newton, the legislator of philosophers, expressed, under the form of conjectures or questions, those things which he was unable satisfactorily to resolve; avoiding rash assertions, which are so fondly taken up by those who wish to seduce mankind.

He conjectured, that these fits of easy reflection and transmission may be occasioned by the vibrations of a *subtil fluid*, in which the ray passes; any ray being disposed to be transmitted when the vibration coincides with it, and to be reflected when it is thereby counteracted.

He also thought that these vibrations might be excited by the mutual action and re-action of light of bodies, and of this medium, at the instant of refraction and reflection.

Sir Isaac, therefore, supposed *two* causes of this disposition to be reflected or transmitted, when rays of light arrive at any new surface. One of them is the regular vibration of the ethereal medium, affecting them through the whole of their progress from the luminous body; and the other the tremulous motion, or irregular vibration of the same medium, at the surfaces of bodies, occasioned by the action and re-action between those bodies and light.

Thus, as stones, by falling into water, put the water into an undulating motion; and all bodies, by

by percussion, excite vibrations in the air; so the rays of light, by impinging on any refracting or reflecting surface, excite vibrations in the refracting or reflecting medium, and by exciting these, agitate the solid parts of the refracting or reflecting body; and that the vibrations thus excited in this subtil refracting or reflecting medium are propagated much after the manner that vibrations are propagated in the air, causing sound, and *moving faster* than the rays, so as to overtake them; and that when any ray is in that part of the vibration which conspires with it's motion, it easily breaks through a refracting surface; but when it is in the contrary part of the vibration which impedes it's motion, it is easily reflected; and, by consequence, that every ray is successively disposed to be easily reflected, or easily transmitted by every vibration by which it is overtaken.

OF THE PERMANENT COLOURS OF NATURAL BODIES, AND OF THE ANALOGY BETWEEN THEM AND THE COLOURS OF THIN TRANSPARENT PLATES.

You have already seen, that the colours of natural bodies consist in a disposition to reflect one sort of rays more copiously than another; and that other bodies are of a different colour, because they reflect rays of a different kind. So that if light consisted only of one kind of rays, there could be only one colour in the world; nor would it be possible, by refractions and reflections, to produce a new one. Thus, in some bodies, all the rays are extinguished but the red-making, and when they are reflected to our eyes, they excite in us the idea of red; and thence we say, that such a piece of cloth, &c. is red; attributing that only to the cloth or wood, which

more particularly arises from the light which dresses them in their various beauty. Thus the ruby absorbs the green, the blue, and the violet; but reflects the red-making rays to our eye, with all their prismatic lustre. The amethyst imbibes the stronger rays, and gives back the violet with milder brightness. The jonquil gives us only yellow, and the hyacinth its vivid blue. Every coloured object may be thus regarded as a partial divider of the rays, separating one or more colours, and confounding all the rest.

Those surfaces of transparent bodies, which have the greatest refracting power, reflect the greatest quantity of light. In other words, bodies, by which the light is more refracted, do likewise more strongly reflect it. Diamonds, which refract the light very strongly, give it, in proportion, a stronger reflection: hence proceed the vivacity of their colours, and their sparkling lustre.

The analogy between refraction and reflection will appear, by considering that the most refractive medium totally reflects the rays of light, at certain degrees of incidence. But the truth of the proposition further appears, by observing the transparent bodies, such as air, water, oil, glass. Iceland crystal, white transparent arsenic, and diamond, have a stronger or weaker reflection, according to the greater or less refractive powers of the mediums that are contiguous to them. Thus at the confine of air and sal gem, it is stronger than at the confine of air and water; and still stronger between common air and glass; still more so between air and a diamond. If any of these be immersed in water, its reflection becomes weaker than before; and it is weaker still, if it be immersed in liquors of a greater refractive power. If water be divided into two parts,
by

by any imaginary surface, there is no reflection at the confines of those two parts; and for the same reason, there can be no sensible reflection in the confine of two glasses of equal density. The reason, therefore, why all pellucid mediums have no sensible reflection but at their external surfaces, where they are contiguous to mediums of different densities, is, that their contiguous parts have precisely the same degree of density.

The least parts of all bodies, though seemingly void of transparency, when viewed in the gross, will be found, if taken separately, to be, in some measure, transparent: and the opacity arises from the multitude of reflections caused in their internal parts. This observation will be easily granted by those who have been conversant with microscopes; for there they are found to be, for the most part, transparent. Nothing seems more opaque, and free from transparency, than the cloaths you wear. Yet let us only examine one of the woollen hairs that go into it's composition, with a microscope, and you will find it to be nearly transparent. Gold, in the mass, lets no light pass through it; but if beaten out extremely thin, we shall then see that it's parts are transparent, like other bodies. If held over a hole, in a darkened window, it will appear of a greenish hue. If gold be composed of transparent parts, we may surely conclude the same of other bodies: and, indeed, you will find very few which, if reduced to sufficient thinness, and applied to the hole, but what are manifestly transparent.

Since light finds a free passage through the least particles, we are to inquire what renders them opaque; and this, by Sir Isaac Newton, is attributed to the multitude of reflections and refractions which take place in it's interior parts; there being, between the parts of opaque or coloured
D d 3 bodies,

bodies, a number of spaces, filled with mediums of a different density from that of the body, as water between the tinging corpuscles with which any liquor is impregnated; air between the aqueous globules that constitute clouds and mists, &c. These spaces cannot be traversed by light, without refracting or reflecting it in various ways, by which it is prevented from passing on in a strait line, which it would do if the parts were continuous, without any such interstices between them; for you have already learned, that reflections are only made at the superficies of mediums of different densities. The opacity of bodies arises, therefore, from the discontinuity of its particles, and the different density of the intervening mediums, and their particles.

This notion of opacity is greatly confirmed by considering, that opaque bodies become transparent by filling up the pores with any substance of nearly the same density with their parts. Thus when paper is wet with oil or water, or when linen cloth is dipped in water, oiled, or varnished, or the oculus mundi steeped in water, &c. they become more transparent than they were before: as filling the pores of an opaque body makes it transparent, so, on the other hand, evacuating the pores of a transparent body, or separating its parts, renders it opaque; as salts, or wet paper, by being dried; horn, by being scraped; glass, by being reduced to powder, or otherwise flawed; turpentine, by being stirred about with water, till they mix imperfectly; and water, by being formed into many small bubbles, either in the form of froth, or, by shaking it together with oil of turpentine, or some other convenient liquor, with which it will not incorporate.

Hence, then, it is in homogeneity you are to seek for the cause of transparency. If there be
many

many pores in a body, and these be filled with a matter differing much in density from the body itself, the light will meet with a thousand refractions and reflections in the internal parts, and will thus be utterly extinguished.

The parts of bodies, and their interstices, must not be less than some definite size, to become opake and coloured.

For the most opake bodies, if their parts be sufficiently divided, as metals, by being dissolved in acid menstrua, &c. become perfectly transparent. And you may remember, that the black spot, near the point of contact of the two plates of glass, transmitted the whole light where the glasses did not absolutely touch; and the reflection at the thinnest part of the soap was so insensible as to make that part appear intensely black, by the want of reflected light.

On these grounds it is, that water, salt, glass, stones, &c. are transparent, for, from many considerations, they seem to be as full of pores as other bodies are, yet their particles and pores are too small to cause reflection in their common surfaces.

The transparent parts of bodies, according to their several sizes, must reflect rays of one colour, and transmit those of others, on the same principles that thin plates or bubbles do reflect or transmit these rays; and this seems to be the ground of all their colours.

That they do so, is plain from various observations; and it is on these principles you may explain the variety of colours seen in some silks, on pigeons' necks; peacocks' tails, and the feathers of other finely coloured birds. If you fix your eye upon a pigeon's neck, and both be kept at rest, only one colour is observable: but if either moves, especially the latter, a different

colour may be seen. Shady silks are woven, with threads of different colours; one arranged longitudinally, the other transversely; and as the greater or less proportion of either of these appears, so one or the other of the colours will prevail. Wet these double coloured objects, dip the variegated feather in water, or the changeable silk in oil, their reflections will be less vivid, and they will return but one uniform shade of colouring. The skin of the camelion is transparent, it's ground being between a pale red and yellow, coloured with a number of small, smooth protuberances of cold, bluish colour. It is endowed with a faculty of blowing up or contracting it's skin at will. This causes the different colours, in appearance, to vary: it, therefore, sometimes appears reddish, at others, blue: the yellow rays of the ground, occasionally mixing with the blue of the protuberances, produces the idea of green; and when placed on a red or yellow substance, it's natural colours are unavoidably heightened.

It is evident, from various phenomena, that a great proportion of the fainter coloured rays are stopped in their passage through the atmosphere, and are thence reflected upon other bodies; while the red and orange rays are transmitted to greater distances. This circumstance explains the blue shadows of bodies, the blue colour of the sky, and the red colour of the clouds, when the sun is near the horizon.

At certain times, when the sky is clear and serene, in the morning and the evening, the shadows cast from opake bodies have been observed to be tinged with blue and green. This circumstance naturally results from the minute particles of the atmosphere reflecting the delicate and most refrangible rays, the blue and violet, for instance; which occasions a predominance of these colours.

The

The blue colour of the sky is accounted for on the same principles; namely, the copious reflection of the blue rays, by the atmosphere, which produces the effect of an arch of that colour, all around us. This is occasionally diversified by the vapours' greater density, which reflect the stronger rays.

The coloured clouds, in particular, which appear towards the morning and evening, when the sun is in or near the horizon, are to be attributed to the same cause. The rays of light traversing a vast extent of atmosphere; the fainter and more delicate rays, as the blue and violet, are detached by repeated reflections of the atmospheric particles; and the stronger rays, as the red, the orange, &c. are permitted to proceed, and reach the clouds, from whence they are reflected. Agreeable to this theory, you may observe, that the sun's horizontal light is sometimes so deeply tinged with the red, that objects illuminated by it frequently appear of a bright orange, and even red. It is observable, that the clouds do not, in common, assume their brighter dyes till the sun is some minutes set, and that they pass from yellow to a flaming gold colour; and thence, by degrees, to red, which becomes deeper and deeper, till the sun leaves them altogether, till at length the disappearance of the sun leaves them of a leaden hue, by the reflection of the blue light from the air. A similar change of colour is observed on the snowy tops of the Alps; and the same may be seen, though less strongly, on the eastern and western fronts of white buildings: St. Paul's church, London, is a good object of this kind, and is often, at sun-set, tinged with a considerable degree of redness. What makes the same colours more rich and copious in the clouds, is their

their semi-transparency, joined with the obliquity of their situation.

It is probably the same coloured light, which being thrown, by the refraction of the atmosphere, into the shadow of the earth, sometimes gives the moon, in a total eclipse, the obscure, reddish colour of brick. For the same reason, the colour of the moon will vary in eclipses, according to the extent of the atmosphere the rays have to traverse.

MR. DELAVAL'S ACCOUNT OF THE PERMANENT COLOURS OF OPAKE BODIES.

I should leave this subject very incomplete, if I did not give you some account of the ingenious observations of Mr. DELAVAL, extracted from a paper communicated by him to the Literary and Philosophical Society of Manchester, and published in the second volume of their memoirs.*

Mr. Delaval was led to this subject, from a persuasion of it's *utility* to those interesting and elegant arts, whose object is the preparation and use of colouring substances: justly observing, that our views of experimental philosophy should not be confined to theory alone, but directed also to it's practical application.

For, in proportion as the principles of any science are unknown or misconceived, the advancement of the arts, and manufactures which depend on them, must, of course, be impeded; for, without those guides, neither much addition, nor any improvement, is to be expected. But when scientific principles are disclosed to the artist, he is

* There is another work of Mr. Delaval, written previous to this paper, which is well worth the reader's attention: it is entitled, "An Experimental Inquiry into the Causes and Changes of Colours, in Opaque and Coloured Bodies."

is enabled to draw, from those original sources, an ample store of useful inventions, by which this art is enriched; and thus, the speculative sciences, by their extension to practical purposes, become objects of great public utility.

The arts of colour-making and dyeing were, in very remote ages, carried to the height of perfection, in the countries of Phœnicia, Egypt, Palestine, India, &c. The inhabitants of those countries excelled, also, in the art of imitating gems, and tinging glass and enamel of various colours. The colours used in very ancient paintings, were as various as those now in use, and greatly superior both in beauty and durability. The paints used by Apelles were so bright, that he was obliged to glaze his pictures with a dark coloured varnish, lest the eye should be offended by their brightness: and even these were inferior to what had been used among the ancient Egyptians. Notwithstanding this perfection in dyeing and colours, we find the Grecians and Romans continually degrading the useful arts. You may consider this as one of the most striking characters that distinguish the philosophy of the ancients from that of the moderns. The *ancients* being chiefly engaged in speculations, that might procure them respect, and attract applause, thought the *useful* arts unworthy their attention: whereas the *moderns* have cultivated and promoted the useful arts; and we find, the Academy of Sciences of Paris, attempting to shed the light of science upon the arts, by publishing a description of them, grounded on the elevated idea, that the industry of a nation cannot fail to be enlightened and increased by a free communication of all the processes it uses; and that the sacrifices it makes, by this publicity, will ever be amply compensated by the advantages it procures.*

But

* Berthollet's Elements of Dyeing.

But why need we go to academies, when we have a fairer and better example in our LORD and SAVIOUR? an example which should teach you to avoid the philosophical *pride* of the gentile, and the pharisaical *self-sufficiency* of the modern infidel. Of our SAVIOUR we read, that having increased in wisdom, he went about doing good. His learning produced not a morose self-complacency, but a lovely affability, and a desire to teach others the glad tidings of joy. The treasures of wisdom were not suffered to rust and canker, locked up from the public by a supercilious reservedness; but out of them he continually dispersed abroad, and gave to the poor in spirit. The sun, at it's rising, found him engaged in this great work; and after it was set, his time was engaged in praying for those whom his days were employed in teaching.

The changes of colour, in permanently coloured bodies, are produced by the same laws which take place in transparent colourless substances; and the experiments, by which they can be investigated, consist of various methods of uniting the colouring particles into larger, or dividing them into smaller masses.

Sir I. Newton made his experiments chiefly on transparent substances; and in the few places where he treats of others, acknowledges his deficiency of experiments. He makes the following remark on those bodies which reflect one kind of light, and transmit another; viz.
 “ that if these glasses or liquors were so thick
 “ and massy, that no light could get through
 “ them, he questions whether they would not,
 “ like other opaque bodies, appear of one and
 “ the same colour, in all positions of the eye,
 “ though he could not yet affirm it from ex-
 “ perience.” It was an opinion of this great
 philoso-

philosopher, that all coloured matter reflects the rays of light; some reflecting copiously the more, others the less refrangible rays. He was, likewise, of opinion, that opaque bodies reflect the light from their anterior surface, by some power of the body, evenly diffused over, and external to it. With respect to transparent coloured liquors, he says, that a transparent body, which looks of any colour by transmitted light, may also look of the same colour by reflected light; the light of that colour being reflected by the farther surface of that body, or by the air beyond it; and then the reflected colour will be diminished, and perhaps cease, by making the body very thick, and pitching it on the back side, to diminish the reflections of it's farther surface, so that the light reflected from the tinging particles may predominate. In such case, the reflected light will be apt to vary from that which was transmitted.

To investigate the truth of these opinions, Mr. Delaval entered upon a course of experiments, with transparent coloured liquors and glasses, as well as with opaque and semi-transparent substances. From these he found, that in transparent coloured substances, the colouring matter *does not reflect any light*; and when, by intercepting the light which was transmitted, it is hindered from passing through such substances, they do not vary from their former colour to any other, *but become entirely black*.

As this incapacity of the colouring particles of transparent bodies to reflect light, was deduced from very numerous experiments, it may be considered as a general law. It will appear the more extensive, if you consider that, for the most part, the tinging particles of transparent substances are extracted from opaque bodies; that the opaque
bodies

bodies owe their colour to these particles, as well as the transparent ; and that by the loss of them they are deprived of their colours.

For making his experiments, Mr. Delaval used small vials of flint-glass, similar to that in my hand ; the form is that of a parallelopiped, the height exclusive of the neck is about 2 inches, the base about an inch square, the neck 2 inches long. The bottom and three sides of each of these vials was covered with a black varnish ; the cylindrical neck, and the anterior side, except at the edges, being left uncovered. He was careful to avoid any crevices in the varnish, that no light might be admitted, except through the neck or anterior side of the vials.

The vials should be perfectly clean, and those liquors that deposit a sediment should not be put into the vials, but at the time when the experiments are to be made. The uncovered side of the vials should not be placed opposite to the window where the light is admitted, because in that situation the light would be reflected from the farthest side of the vial ; smooth black substances, reflecting light powerfully, are best situated when the uncovered side forms a right angle with the window.

Taking all these precautions, he viewed a great number of solutions both of coloured metallic salt, and of the tinging matter of vegetables, observing that the colour by reflection was black, *whatever it might be* when viewed by transmitted light. If these colours were, however, spread thin upon a white ground, they appear of the same colour as when viewed by transmitted light ; but on a black ground they afford no colour, unless the black body be polished, in which case the reflection of light through it produces the same effect as transmission.

The

The experiments made with coloured glasses, were in many respects analagous to those with transparent coloured liquors. For these he made several parcels of colourless glass, composed of borax and white sand. The glass was reduced to powder, and afterwards ground together with the ingredients, by which the colour was to be imparted; a method he found preferable to the usual mode of tinging glasses, as they became little inferior in lustre to real gems.

The result of all his experiments was, that when matter is of such thinness, and the tinge so dilute, that light can be transmitted through it, the glasses then appear vividly coloured; but when they are in large masses, and the tinging matter is more densely diffused through them, they appear black, for these as well as the transparent liquors shew their colour only by transmission.

Having in this manner formed pieces of such glass, two inches thick, he inclosed them in black cloth on all sides, except their anterior and farther surfaces. In this situation each of them shewed a vivid colour when light was transmitted through them, but when the posterior surface was likewise covered with the cloth to prevent the transmission, no other colour but black was exhibited.

From these phenomena he drew the following inferences:

1. *That the colouring particles do not reflect any light.*
2. *That a medium, such as is described by Sir I. Newton, is diffused over both the anterior and posterior surfaces of the plates, whereby objects are equally and regularly reflected as by a mirror.*

Our author next considers the colouring particles themselves, pure and unmixed with other media. To procure masses made up of such particles, several transparent coloured liquors were reduced

duced to a solid consistence by evaporation; by employing a gentle heat the colouring matter will not be injured, and may have it's particles again separated by water or other fluids, and tinging them as before. In this state also the colouring particles reflect no light, and therefore appear uniformly black, whatever be the substance from which they may have been extracted.

He endeavours to prove by experiments on the colouring particles of opaque bodies, that these colours are produced on the above-mentioned principles; that they seem black when very dense, but shew their proper tinge when spread thin upon a white ground.

The green of grafs, and leaves of plants being obtained by digesting them in rectified spirits of wine, and placed in one of the above-mentioned vials, the part in the neck transmitted the vivid green, but that contiguous to the uncovered side of the vial was black.

After the colour had been totally extracted, the leaves remained apparently unaltered as to figure or texture, but were entirely white, or of a white tinged with brown; red, blue, and purple flowers were also digested with spirits of wine, all of which yielded their colouring matter to the spirit, and became white when deprived of it. From most of these flowers the spirit, however, either acquired no tinge at all, or only a very faint one; but when acidulated it became red, and by the addition of an alkali became blue, purple, or green, according to the quantity of the alkali and the nature of the infusion. In these states all of them, when viewed by transmitted light, or poured upon a white paper, shewed their colours, but universally appeared black by reflection. Other experiments were tried with other flowers, but the final result was the same, *no colour by reflection.*

White

White paper, linen, &c. may be tinged of any of these colours, by dipping them in the infusions; and the consideration of the manner in which the colours are imparted to linen, affords much insight into the manner in which natural colours are produced. It has been already observed, that when the colouring matter of plants is extracted from them, the solid fibrous parts, thus divested of their covering, display their natural *whiteness*. White linen, paper, &c. are formed of such fibrous vegetable matter, which is bleached by dissolving and detaching the heterogeneous colouring particles: when these therefore are dyed or painted with vegetable colours, it is evident that they do not differ in their manner of acting on the rays of light from natural vegetable bodies; both yield their colours by transmitting through the transparent coloured matter the light which is reflected from the white ground.

This *white matter* ever exists without any considerable mixture in plants while they are in a state of vegetation, as cotton, white flowers, the pith, wood, seeds, roots, and other parts of several kinds of vegetables. When decayed leaves of trees have been long exposed to the atmosphere, their coloured juices are sometimes so perfectly extracted that their fibres appear white.

Mr. Delaval has rendered ashes *intensely white*, by carefully calcining them, and afterwards grinding with a small proportion of nitre, and exposing them to such a degree of heat as would cause the nitre to deflagrate with the remaining quantity of phlogiston. Lastly, the ashes were digested with the marine acid, in order to dissolve the ferruginous matter diffused through them, and repeatedly washing the remainder in water.

Hence it would appear, that the earth which forms the substance of plants is white, and separa-

ble from that substance which gives to each it's peculiar colour; that whenever it is pure and unmixed, or diffused through colourless media, it shews it's native whiteness, and is the only vegetable matter endowed with a native whiteness. This white matter may be discovered by other means besides burning; thus roses may be whitened by exposing them to burning sulphur, and the colour may be again restored by the addition of an acid either mineral or vegetable.

Thus it appears that the colouring matter of the flowers is not discharged or removed, but only dissolved by the phlogiston, and thereby divided into particles too minute to exhibit any colour. In this state, together with the vegetable juice in which they are diffused, they form a colourless transparent covering, through which the white matter of the flowers is seen untinged. The colouring matter of plants consists, according to Mr. Delaval, principally of inflammable matter, and their solubility in and union with phlogiston.

Colour is destroyed by the rays of the sun. Thus dyed silk and other substances of that kind, when exposed to the sun's light, are deprived of their colour in every part on which the rays are allowed to act; whilst those preserve their colours, which are defended from the light. The colours, thus *impaired*, may be restored, if acids are employed while the injury is recent.

In a word, all Mr. Delaval's experiments shew, that the colouring matter of plants does not exhibit any colour by reflection, but by transmission only; that their solid earthy substance is a white matter, and that it is this part that has the property of reflection; that the colours of vegetables are produced by the light reflected from this white, and transmitted from thence through the coloured coat or covering which is formed on it's surface
by

by the colouring particles; that whenever the colouring matter is either discharged or divided by solution into particles too minute to exhibit any colour, the solid earthy substance is exposed to view, and displays that whiteness which is its distinguishing characteristic.

Mr. Delaval having settled this point, next proceeded to examine the coloured parts of animal substances, and found them exactly similar with regard to the manner in which the colour was produced, to the vegetable substances already treated of. The tinctures and infusions of cochineal and kermes yield their colours when light is transmitted through them, but shew none by reflection: on diluting fresh ox-gall with water, and examining it in the above-mentioned phials, the part of it viewed by transmitted light was yellow; but the anterior surface in the lower part of the phial was black, and reflected no colour. Flesh derives its colour entirely from the blood, and when deprived of it the fibres and vessels are perfectly white; as are likewise the membranes, sinews, and bones, when freed from their aqueous and volatile parts. The florid red colour of the flesh arises from the light which is reflected from the white fibrous substance, and transmitted back through the red transparent covering, formed by the blood on every part.

In like manner the red colour of the shells of lobsters after boiling, is no more than a mere superficial covering, spread over the white calcareous earth of which the shells are composed, and may be removed from the surface by scraping or filing. Before the application of heat this superficial covering is much denser, insomuch that in some parts of the shell it appears quite black, being too thick to admit the passage of the light to the shell and back again; but where this transparent blue

colour of the unboiled lobster is thinner, it constantly appears like a blue film. In like manner the colours of the eggs of certain birds are entirely superficial, and may be scraped off, leaving the white calcareous earth exposed to view.

The case is the same with feathers, which owe their colours entirely to a very thin layer of some transparent matter upon a white ground; this was ascertained by scraping off the superficial colours from certain feathers, which were strong enough to bear the operation, and which separated the coloured layers from the white ground on which they have been naturally spread. The lateral fibres cannot have their colours separated in this manner; but their texture, when viewed by a microscope, seems to indicate that their colours are produced on them by no other means than those already related. In a word, he found that in all the animal subjects he examined, the colours were produced by the transmission of light from a white ground through a transparent coloured medium.

The coloured substances of the mineral kingdom are very numerous, and belong principally to two classes, earths and metals; the former, when pure, are all white, and their colour arises from phlogistic or metallic mixtures. Calcareous earths, when indurated, constitute marble, and may be tinged with various colours by means of metallic solutions, all which are similar in their nature to the dyes put upon silk, cotton, or linen, and invariably proceed from the same cause, the transmission of light through a very thin and transparent medium. Flints are formed from siliceous earths, and owe their colour to the state of fire within them; when sufficiently heated, they are rendered white by the loss of the inflammable matter which produced their colour; when impregnated with metals, they form agates, cornelians, jasper, and coloured

coloured crystals. The coloured gems also receive their different hues from metals, and may be imitated by glasses tinged with such inflammable or metallic matter as entered into the original substances, all exhibiting their various tints in the same manner, by the transmission of light from a reflected white ground.

Even the colours of metals, according to Mr. D. are produced in the same manner. Gold exhibits a white light tinged with yellow; this is grounded on an experiment of Sir I. Newton, who says, that gold in a white light appears of the same colour as in the day-light, but that on intercepting a due quantity of yellow-making rays, it will appear white like silver, which shews that it's yellowness arises from an excess of the intercepted rays, tinging that whiteness with their colour when they are let pass.

A solution of silver is pellucid and colourless; a solution of gold transmits yellow, but reflects no colour. This metal, when united to glass, yields no colour by reflection, but only by transmission. All these circumstances seem to indicate, that the yellow colour of gold arises from a yellow transparent matter, which is a constituent part of that metal, and that is equally mixed with the white particles of the gold, and transmits the light reflected by them; in like manner as when silver is gilt, or foils are made by covering white metals with transparent colours. But these factitious coverings are only superficial, whereas the yellow matter of gold is diffused throughout the whole substance of the metal, and appears to envelope and cover each of the white particles; the yellow matter bears to the white about the same proportion that the yellow-making rays, which were intercepted, bear to all the other rays comprised in the white light of the sun.

Sir Isaac Newton has shewn, that when the spaces or interstices of bodies are replenished with media of different densities, the bodies are opaque; that those superficies of transparent bodies reflect the greatest quantity of light, which intercede media, that differ most in their refractive densities; and that the reflection of thin transparent substances are considerably stronger than those made by the same substances of a greater thickness. Hence the minute portion of air, or of the rarer medium, which occupies the pores or interstices of dense bodies, is a minute white substance. This is manifest in the whiteness of froth, and of all pellucid colourless substances, such as glass, crystal, or salts reduced to powder, or otherwise flawed; for in all these instances a white light is reflected from the air or rarer medium, which intercede the particles of the denser substance, whose interstices they occupy.

Hence also we see why white opaque substances are rendered pellucid by being reduced to uniform masses, whose component parts are every where nearly of the same density; for as all pellucid substances are rendered opaque and white by the admixture of pellucid colourless media, of considerably different densities, they are again deprived of their opacity, by extracting these media, which keep their particles at a distance from each other: thus froth or snow, when resolved into water, lose their whiteness, and assume their former pellucid appearance. In like manner the opaque white earths are by proper fluxes reduced to pellucid colourless glass; because all reflections are made at the surfaces of bodies differing in density from the ambient medium, and in the confines of equally dense media there is no reflection.

As the calces of metal are capable of reflecting their colours by the intervention of air, so,
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when mixed with oil in making paints, they always assume a darker colour, because the excess of the density of oil over air forms a sensible difference, when comparatively considered with respect to the specific gravity of the rarer metals. From this cause perceptibly less light is reflected from the *moleculæ* of oil than from those of air, and consequently the mass appears darker. The case is however different with such paints as are formed of the denser metals, as vermilion, minium, &c. for though oil differs very considerably from air in it's specific density, yet it also differs very much in this respect from the denser metallic powders; and the *moleculæ* of oil, which divide their particles, act upon the light so strongly, that the reflection of light occasioned by them cannot be distinguished from those which are caused by rarer media. Hence, when we mix vermilion or minium with oil, the colour is not sensibly altered.

All the earths, which in their natural state are of a pure white, constitute transparent colourless media when vitrified with proper fluxes, or when dissolved in colourless menstrua; and the saline masses, obtainable from their solutions, are transparent and colourless, while they retain the water which is necessary to their crystallization, and are not flawed or reduced to powder: but after their pores and interstices are opened in such a manner as to admit the air, they become white and opaque by the admittance of that rare medium. The earthy particles, which form the solid parts of bodies, generally exceed each other in density; consequently these particles, when contiguous to the rare media already mentioned, must reflect the rays of light with a force proportionate to their density. The reflective power of bodies does not depend merely upon their excess of density, but upon their difference of density with respect to the sur-

rounding media. Transparent colourless particles, whose density is greatly inferior to that of the media they come between, also powerfully reflect all sorts of rays, and thereby become white; of this kind are the air, or other rare fluids, which occupy the interstices of liquors, and in general of all denser media, where such rare particles are admitted.

Hence we may conclude, that white opaque bodies are constituted by the union or contiguity of two or more transparent colourless media, differing considerably from each other in their reflective powers. Of these substances we have examples in frothy emulsions, or other imperfect combinations of pellucid liquors, as milk, snow, calcined or pulverized salts, glass or crystal reduced to powder, white earths, paper, linen, and even those metals which are called white by mineralogists: for those metals do not appear white unless their surfaces be rough; as in that case only there are interstices on their surface sufficient to admit the air, and thus make a reflection of a white and vivid light.

The polished surfaces of metallic mirrors reflect the incident rays equably and regularly according to their several angles of incidence, so that the reflected rays do not interfere with each other, but remain separate and unmixed, and therefore distinctly exhibit their several colours. Hence it is evident, that white surfaces cannot act upon the light as mirrors, because all the rays which are reflected from them are blended in a disorderly and promiscuous manner.

The foregoing phenomena give us some insight into the nature and cause of opacity, as they clearly shew, that even the rarest transparent colourless substances, when their surfaces are adjacent to media differing greatly from them in refractive

refractive power, may thereby acquire a perfect opacity, and may assume a hue and resplendence similar to that of white metals; that the rarer pellucid substances cannot by the sight be distinguished from the dense opaque metals; and this similarity to the surface of metals not only occurs; when from the roughness of their surfaces they resemble polished metals in whiteness, but also when from their smoothness they resemble the polished surface of metals.

Metals seem to consist entirely of transparent matter, and to derive their apparent opacity and lustre solely from the copious reflection of light from their surfaces. The analogy between metals and transparent media, as far as concerns their optical properties, will appear to you from the following considerations: 1. All metals dissolved in their proper menstrua are transparent. 2. By the union of two or more transparent media, substances are constituted which are similar to metals in their opacity and lustre, as plumbago and marcasites. 3. The transparent substances of metals, as well as those of minerals, by their union with inflammable matter, acquire the strong reflective powers from which their lustre and opacity arise. 4. The surfaces of pellucid media, such as glass or water, assume a metallic appearance, when by their smoothness, difference of density with respect to the contiguous media, or any other, they are disposed copiously to reflect the light.*

From these considerations it is evident, that opaque substances are constituted by the union or contiguity of transparent colourless media, differing from one another in their reflective powers; and that when the common surface, which comes between such media, is plane, equal, and smooth,

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* For further particulars, &c. &c. see Mr. Delaval's paper, "Memoirs of the Manchester Society," vol. 2.

it reflects the incident rays equally and regularly as a mirror; but when their surface is rough and unequal, or divided into minute particles, it reflects the incident rays irregularly and promiscuously in different directions, and consequently appears white.

When the interstitial vacuities of bodies are so disposed, that the light can preserve it's rectilinear course through them, such bodies appear luminous throughout, and are visible in their internal substance; but when their constitution is such as will not allow a free passage to the light, they are then visible only by those rays which are reflected from their surface, and their internal surface is cold and dark.

From various considerations it appears, that the chemical properties of bodies have a considerable influence on their colour; for, doubtless, a force which acts powerfully in refracting the rays, must likewise influence their reflection; and it is hardly to be doubted but that the action of fire has a considerable share in the production of colours; indeed it's share in the operations of nature is so considerable, that it would be strange if it should be excluded from this more curious part.

By comparing the refractive power of different bodies, NEWTON found that inflammable substances possess it in a much greater degree than such as are not inflammable. From his observations on this subject, he drew the wonderful conclusion,* that the *diamond* contained a large quantity of *inflammable* matter; that *water* was an intermediate substance between inflammable and un inflammable bodies, and that it supplied vegetables with the inflammable principle; which truths have been seen and demonstrated only in the present day.

Bodies,

* Berthollet's Art of Dyeing, p. 6.

Bodies, not transparent in their ordinary state, may be rendered so either by relaxing their parts with heat, so that the light may pass through them more easily, or by giving some new direction, together with an additional force, to the matter of light. Mr. Hawksbee was very much surprised to find, that the sealing-wax, and the pitch, within side a glass globe, became so transparent when the glass was whirled about and rubbed with the hand, that the fingers might be plainly seen on the other side through the coating. Oil is condensed, when cold, into a sort of globules impervious to the light; but when these globules are dissolved, and opened by the action of fire, the oil not only becomes transparent, but appears as bright and shining as if the light were a natural part of it's substance.

Many heterogeneous fluids grow dark and muddy with cold, but may soon be clarified again by the application of a moderate heat: red-port wine is sometimes as foul as if brick-dust was mixed with it, but will soon become bright and clear before the fire.

The quality of transparency is given, by a wise ordination of Providence, to the fluid substance of water, which is so necessary to the life of all animals. Transparency renders glass most valuable; the value of gold is arbitrary, but the worth of glass is intrinsic; it's cleanliness and transparency recommend it to our use for the common purposes of life, and render visible the most curious and subtil processes of chemistry and philosophy: in optics, it assists the aged, and gives to man an insight into the wonders of creation. *

* Jones's Physiological Disquisitions, p. 86,

LECTURE XXI.

OF PHOSPHORIC BODIES.

THE more the nature of light is investigated, the more it's relation to fire is discovered: many proofs of this you have already seen, many more will occur in treating of phosphoric bodies. As I have already shewn you, that fire is received and retained in bodies under the form of *heat*; I have now to shew you, that it is also retained in most substances under the form of *light*.

By phosphorus we in general mean those substances which shine in the dark, without emitting heat. Phosphorus is divided into several kinds, known by the names of the *Bolognian* phosphorus, *Mr. Canton's* phosphorus, *Baldwin's* phosphorus, phosphorus of *urine*, &c. &c. Besides these, it has been found that the far greater part of terrestrial bodies, upon being exposed to the light, will appear luminous in the dark. This circumstance has occasioned some writers to divide the phosphori into two classes, namely, such as require to be exposed to the light either of the sun or some artificial fire, before they become luminous; and such as do not. Of the first kind are the *Bolognian* phosphorus, *Mr. Canton's* phosphorus, the phosphorus from earths, &c.; of the latter kind are rotten wood, the skins of fishes, and the phosphorus of urine. There is another class which becomes luminous by friction or vibration, as sugar, and the solution of phosphorus in spirits of wine.

It has been said, "that philosophy was never
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“under more obligation to what is called *chance*,
“than with respect to the discovery of the pro-
“perty of imbibing of light, which was once
“thought to be peculiar to a certain fossil in the
“neighbourhood of Bologna, but is now found in
“many other substances. Not only was a *single* and
“leading fact, but a *whole series* of facts the result
“of casual observation.” You are, I hope, better
learned, and will enter your protest against this
opinion; for you know that such an opinion, if
embraced, would deprive you of that satisfaction
of mind which arises from a strong and well-
grounded apprehension of a *Divine Providence*, and
of your being constantly under a gracious protec-
tion that will guard you from every evil unproduc-
tive of greater advantage. It is indeed the main
basis of prudence and benevolence, as it ensures to
you, that whatever you do well shall be attended
with success either at present or in futurity, and
thus making the good of your fellow-creatures your
own highest interest. As this opinion is thus dan-
gerous, it can be no improper digression to consider
it more attentively, and the more so as you will
find another writer, to whom I shall have occasion
to refer you on the subject of phosphorus, ac-
knowledging that it was accident which lifted up
the veil of nature to him, and attributing to the
same blind cause the greatest discoveries that have
been made by others.

In common discourse we often indeed speak
of *chance* or *fortune*, as a power influencing the af-
fairs of men, and having a principal share in the
direction of all events; as frequently baffling the
skill of the wise, the valour of the brave, and the
strength of the mighty; as turning the scale of vic-
tory, and determining the success of all enter-
prizes. But if you examine the idea of chance
philosophically, you will see that it is neither agent

nor power, nor has any other existence except *in our own ignorance*; for whatever is ascribed to chance or fortune, we should see performed by other causes, if we had sagacity to discern them.

Chance is no cause of any thing, and serves only to express our *ignorance* or *uncertainty* of the manner in which other causes operate; and in this sense may be applied to the most cogent necessity or most deliberate design, where we know not the tendency of the one, nor the purpose aimed at by the other. What is esteemed more casual than weather? Yet nobody doubts of the air being moved, the vapours rarified, and the clouds condensed, according to a certain impulse received from mechanical causes; but because no mathematician nor naturalist can investigate those causes so as to calculate what they will produce, we say, the farmer depends upon chance to bring his corn to maturity, and give him a favourable season for his harvest: yet if we were acquainted with the respective qualities, and exact proportions, of the causes from whence they proceed, we might calculate the variations of the weather, as well as we now do the changes and eclipses of the moon. So that an event, happening by chance, does not elude the operations of necessary causes, nor the acts of free agents, nor the provisions of wisdom; for the effects of all three will appear casual when we cannot foresee them. And when it is said any thing is discovered by chance, or that fortune has had such an influence upon our affairs, no more should be understood by these expressions, than that we are ignorant of the causes acting around us, and affecting the success of our measures. Before accident takes place in those events where our agency has no concern, there must have been natural causes in motion previous to any thing thus appearing to fall out accidentally among them;

them; and it is only our ignorance of their concurrence and powers that gives chance a title to the production.

Inventions, as we have on a former occasion observed, may appear accidental, and so indeed they are with respect to us, for no man could have seen before hand the day when they would happen: but accidents arise from certain causes lying in train to produce them; when, and in what manner they shall come to pass, must be referred to the DISPOSER of all events. It is frequent in philosophical disquisitions, that the same inquiry produces very different discoveries. The attention paid to the immediate object of investigation does not shut the eye of the observer against any thing else that may offer; and the state into which the subject of examination is put, in order to favour an expected event, often gives origin to another not less interesting.

Nature is nothing more than a conveyancer, whose channels we can in some measure trace, conducting activity from one substance to another; and chance grows like an excrescence from the situation, the circumstances, or mutual concurrence of other causes. We have no experience of any thing that can act otherwise than by transmitting an operation already begun. Volition is the only power, we know of, that is capable of beginning an action, or giving an impulse it did not first receive. And whoever supposes a substance involuntarily self-moving, or causing a new impulse not in being before, builds upon a mere hypothesis, without any fact, within the compass of his observation, to support it; whereas, he who holds the contrary, does it because experience of his own actions teaches him that he begins them himself, but that every thing acting involuntarily proceeds in

another manner, only carrying on an operation begun by some other agent.

Our views of providence must be partial and imperfect at best, wherefore much of the wisdom of God will appear foolishness to man; and so does wisdom always appear to such as have not capacity to discern the justness of her measures, nor the ends for which they were pursued: but the more attentively you observe the luminous tracts, you will find them spreading further and further into the dark and exceptionable, and they will open before you an ample field for contemplation. For you will discover wheel within wheel, be able to trace the connection between many of them, discern their exact adjustment to each other, and perceive one adapted to answer various purposes, till at last you will be ready to believe with PLATO, that the whole world is a tissue of causes and effects, wherein nearly or remotely every thing has an influence upon the rest. From hence we may conclude, not only that the young ravens are fed, and the lilies of the field arrayed in the glory of Solomon by the DIVINE provision; but that of two sparrows which are sold for a farthing, not one of them falleth to the ground; not a hair is lost of the number upon our heads; not an atom stirs without the permission of our HEAVENLY FATHER.

Thus also God has been pleased by a long and extraordinary series of events, continuing from the infancy of mankind, to nourish up a religion whereby purer sentiments of himself, and a more extensive charity, may be introduced among the vulgar; and has in his wisdom raised up two trees, *philosophy* and *religion*, from little seeds, and by slow and successive gradations, whose influence when mutual continually tends to purify and *melliorate* mankind, but when set at too great a distance from each other, philosophy becomes a vain babbler,

babbler, and religion a superstitious enchantress. When properly mingled, their branches grow more vigorous, extend over a larger compass, and bear fruits of more general use, co-operating in that great design which has been carrying on from the earliest accounts of history by a remarkable course of providence, calculated for the benefit of the human race in general, distinct from that respecting particular persons; intended to introduce a perfect rectitude of sentiment both in the understanding, and inferior faculties of the mind.

Too numerous are the instances to be noticed in these Lectures, and they would lead me too far from the general plan of the work; but one or two I cannot refrain from mentioning. You know how much the art of printing has contributed to the advancement of learning; but this was not the discovery of any philosopher; the world had been long acquainted with the method of stamping inscriptions upon medals and seals, which one would think might naturally have led the ingenious to contrive how to stamp the pages of a book, yet was it never thought of until the appointed time written in the book of heaven.

The magnetic power of the load-stone was known 2000 years ago, but remained an object of idle curiosity for ages, until the use of the needle was discovered; when it opened to us a new world, gave a readier access to the remotest regions of the old, became a means of communicating knowledge, and familiarizing the nations of the earth.

Gunpowder is said to have been discovered by a monk trying experiments, without expectation of any such result; but how greatly has it changed the polity of nations, and civilized the rugged manners of war, making it depend more upon science than bodily strength or personal courage, and uniting the civil with the military interest!

rest! And in remote consequence of these inventions concurring with other incidents in the amazing series, mankind is become better united and civilized; every nation has some intercourse with others, and the more barbarous gradually take a tincture from the more humane.

Let us now return to our phosphoretic bodies, and first of the Bolognian phosphorus. This was discovered about the year 1630, by Vincenzo Cascariolo, a shoe-maker of Bologna, who being in quest of some chemical secret, among other things tried a calcination of some stones to be found in the neighbourhood of that city; and observed, that whenever this stone was taken into the dark, after having been exposed to the light, it was plainly visible by a light issuing from itself, continuing to appear so for some time, when it became invisible; but upon returning it to the light, and then carrying it back to its former situation, it exhibited the same appearance as before.

Of bodies that give light in the dark there are several kinds; for some bodies throw out light *spontaneously*, and others upon being *excited*. Of the former kind some shine with a *natural light*, as glow-worms, dates, and a good many aquatics; others possess an *adventitious light*, as rotten woods, and the flesh of some quadrupeds and birds. These last are not naturally phosphoric, but owe that property to some particular cause, which generally is *putrification*, and sometimes an insensible change in the natural constitution of the parts.

Those bodies which become phosphori upon being *excited*, or whose phosphoretic property is at least assisted by excitation, may be distributed into different species according to the mode in which this property is brought into action. These modes are *attrition*, *agitation*, *heat*, *the free admission of air*, and *being exposed to the external light*.

Bodies

Bodies of every kind become phosphori by *attrition*, provided they can bear that force of friction which is sufficient to produce the reluctant light that is hid in their substances; *agitation* agrees mostly with liquid substances, as sea-water.

The emerald phosphorus, and many gems, and amongst these not a few diamonds, the lapis lazuli, and a great part of the mountain crystals, become phosphoric by the application of *heat*.

The free admission of air not only produces light in using the phosphorus of Konkel, but even a blaze of fire where friction is used. The phosphorus of Homberg burns also furiously upon the approach of air.

The last class, those which act after *being exposed to the external light*, are exceeding numerous; there seem but two substances which do not emit light when tried in this way, except water, in it's fluid state, and metals. All bodies then whatever, except water and metals, have a power of imbibing light, and when placed in proper circumstances, of emitting it again.

This has been fully proved by the experiments of Mr. Beccari* of Bologna, and Mr. Wilson, which have been made in the most satisfactory manner; indeed, so great has been their diligence, that there are but little hopes of adding any thing considerable to what they have done.

A very weak light can only be visible in great darkness. When the sun is in it's meridian splendor, the moon and stars are totally obscured; and yet when his superior light is withdrawn, how plainly the moon and stars appear. Art will produce a degree of darkness far exceeding that of the night, and in such darkness the weakest light will become visible. Mr. Wilson, therefore, to judge

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* Not Beccaria the electrician.

of the illumination of bodies, when brought from the light, made his experiments in a closet about 6 feet by $5\frac{1}{2}$ feet, the height about 9 feet. It was painted black, or covered with black baize in every part, and had two doors which were 5 or 6 inches broader and longer than the space to enter at. There were two curtains of black cloth over the hole where the hand was occasionally put out, to expose bodies to the light; the outer one and inner one each consisted of three doubles: all these were considerably larger than the hole, which was about 15 inches diameter, and opened to the south. There were small leaden weights fastened to the bottom of each curtain, to preserve them in their places when the hand was drawn into the room; two curved pipes were fitted to the closet, one communicating with the external air from the top of the room, the other from the bottom, for the sake of breathing freely; by means of this closet any substances could be easily exposed to the light, or withdrawn from it.

Numerous, and well worthy of your attention, are the experiments made by *Wilson* in this closet; here almost every substance was found to be phosphoretic: but calcined oyster-shells, and white paper, possessed this power in an eminent degree. A piece of paper with a key being exposed to the light, and again taken into the room, the key was then removed, and there remained as much of the paper dark as had been covered by the key, leaving a black space exactly of the same figure as the key. A gentleman's hand, and part of a ruffle, being dipped in the light, and then suddenly withdrawn, appeared luminous; and as every other part of the body was dark, it looked like a hand with a bit of ruffle suspended in the air, so that the human body was found like others to be phosphoric.

Though

Though fluid water is incapable of emitting light, yet when condensed into the form of ice or snow, it assumes it, like other species of matter. This accounts for the light afforded by snow lying on the ground, even when the heavens are involved in utter darkness; being exposed to the light all the day, it absorbs a great deal of light, and is thereby enabled to give out a considerable quantity in the night.

It is probable that all the bodies with which we are surrounded are sufficiently endued with this phosphoretic property, to enable animals to find their food in the night. To this it may be added, that the eyes of animals are better constructed for collecting light than the human eye: thus the substance spread out behind the retina of cats, owls, &c. is white, which reflects the most light; that behind the retina of graminivorous animals is green; lastly, that in the human eye is black; hence we require more light than animals to discover objects, but our vision is more perfect.

From the foregoing experiments it appears, that the world is stocked with a variety of occasional phosphori, from which light is insensibly evaporating where we should never have looked for it, nor could possibly have detected it, but for the subtle mode of examination contrived by Beccari and Wilson.

OF CANTON'S PHOSPHORUS.

To prepare this, take some oyster-shells, and calcine them, by keeping them in a good coal fire for half an hour; let the purest part of the calx be pulverized and sifted; to three parts of this powder add one of the flowers of sulphur, and mix them well together; put the mixture into a crucible, and ram it tightly therein; then let it be

F f 3

placed

placed in the middle of a fire, where it must be kept red-hot for an hour at least, and then set to cool. When it is cold, turn it out of the crucible, and cutting or breaking it to pieces, scrape off upon trial the brightest parts, which, if good, will form a white powder, which you may preserve by keeping it in a dry phial, with a ground stopple.

The quantity of light which a little of this phosphorus gives when first brought into a dark room, after it has been exposed for a few seconds to the light of the day, is sufficient to shew the hour by a watch, if the eyes have been previously shut for one or two minutes.

By this phosphorus you may represent celestial objects, such as Saturn and his ring, the phases of the moon, &c. If the figures of them made of wood, be wetted with the white of an egg, and then covered over with the phosphorus, a flash from the discharge of an electrical jar will illuminate the phosphorus as well as the light of the day.

By a variety of experiments made with this phosphorus it appears, that when it had emitted all the light it could in the common state of the atmosphere, it would emit more on the application of heat, but that the same degree of heat would only render it luminous for a certain time.

Let one end of a bar of iron of about an inch square, or a poker, be made red-hot, and laid horizontally in a darkened room, till, by cooling, it ceases to shine, or is barely visible; then bring a little dry phosphorus, which has been exposed to the light, in a glass ball hermetically sealed as near the hot iron as possible; and the phosphorus, though invisible before, will in a few seconds begin to shine, and will discharge it's light so very fast, as to be entirely exhausted thereof in less than a minute,

minute, and will shine no more by the same treatment till it has been again exposed to the light. By this heat light received from a candle, or even from the moon, may be seen several days after; and phosphorus that will afford no more light by the heat of boiling water, will shine again by the heat of hot iron. By means of this heat, phosphorus, which had been kept in darkness more than six months, was found to give a considerable degree of light.

Mr. *Wilson*, in his treatise on phosphori, has made a variety of experiments on oyster-shells calcined, and combined with nitrous acid, and without it; in all cases they acquired the phosphoric quality in a very high degree. He poured some aqua fortis, previously impregnated with copper, on a quantity of calcined oyster-shells, so as to form them into a kind of paste; this paste was put into a crucible in a pretty hot fire, for about 40 minutes. Having taken out the mass, and waited till it was cool, he presented it to the external light; on bringing it back suddenly to the dark, he was surprised with the appearance of a variety of colours like those of the rainbow, but much more vivid. In consequence of this appearance of the prismatic colours, he repeated the experiment in various ways; combining the calcined oyster-shells with different metals, and metallic solutions; with the different acids, alkaline, and neutral salts; as well as with sulphur, charcoal, and other inflammable substances; and by all of these he produced phosphori which emitted variously coloured light.

What is more remarkable, he found that oyster-shells possessed the phosphoretic quality, and would exhibit the prismatic colours, in a surprising degree; and for this purpose nothing more was

necessary than to put them in a good sea-coal fire, and keep them there for some time. On scaling off the internal yellowish surface of each shell, they become excellent phosphori, and exhibit the most beautiful and vivid colours.

From Mr. Wilson's experiments it appears, that fire or inflammable matter is essentially necessary towards producing prismatic colours in phosphoric substances; that there is no particular disposition in the shell to exhibit any particular colour without the aid and assistance of the inflammable principle; and that the several parts of the shells exhibit such colours as correspond with the different quantities of inflammable matter that they respectively contain.

The inflammable principle appears to be so weakly combined, that it is easily disengaged in consequence of the action of light.

Mr. Beccaria attempted to shew, that phosphorus emitted the very same light that it received, and no other; and Dr. Priestley concluded from hence, that Zanotti was wrong in asserting, that phosphori shine by their *own native light*, after they have been kindled by *foreign light*. Zanotti appears, from Mr. Wilson's experiments, to have been considerably nearer the truth than Dr. P. apprehends; as he seems fully to have disproved, by his numerous and accurate experiments, the opinion of Beccaria.

The experiments on phosphori may perhaps be accounted for by considering, that as an heated iron, which is dark by day-light, appears red and fiery when carried into a dark room, having acquired but a part of that ignition which renders it luminous in the open day-light; so other bodies are capable of an *incipient ignition*, which is perceptible to the eye in artificial darkness; and it is
this

this *incipient ignition* which brings them under the denomination of *phosphori*. It is remarkable, that a degree of light is discernible in heated oil; when viewed in such a dark medium; and that even cold water does not immediately extinguish the light imbibed by sugar, gum, paper, &c.

It has long been observed, that bodies, when beginning to putrify, emit light: this has been observed in meat, fish, and particularly in wood; in meat the softest parts are most luminous, it looks, when in this state, as if sprinkled over with gems, and upon touching it the luminous particles come off on your fingers: this however does not take place before a certain degree of putrefaction is induced, and ceases after it has proceeded to a further degree.

The luminous appearance of the sea has long been known, and variously accounted for; it now seems to be generally attributed to a phosphoretic appearance, arising from putrified materials, from fish and vegetables, which rise to the surface of the water in the form of scum, and when agitated yield more light than when at rest.

There is a remarkable difference between the light of rotten wood, fishes, and that of phosphorus of urine, even when it is not in an ignited state; for this last does not cease to be luminous even when included within an exhausted receiver; the contrary of which happens to rotten wood and fishes. When kept in water, and placed in warm air, the phosphorus of urine discharges such large and bright flashes into the air above it, as are apt to surprise, and even to frighten those who are unacquainted with it.

Phosphori, in the most extensive meaning of the word, may be considered as bodies giving light; though more properly they are those bodies which give a faint light, (visible only in the dark)
upon

upon being rubbed, or after having been exposed to the influence of light.*

Bodies shine in the dark in consequence of an excess in their heat, and by the emission of this light the heat is in some degree dissipated; the substance of the body is thus changed in its temperature, or in relation to heat.

Bodies emit light also in consequence of the resolution of phlogistic matter, which had been contained in their substance or composition.

But bodies also emit light without being sensibly affected in their temperature, or having the composition of their substance changed; this change may be effected by that active principle, which there are many reasons for supposing to reside on the surfaces of bodies.

That particular species of bodies which have a peculiar power in their substance, by which incident light is reflected, or which have a power of absorbing light, do not become phosphoretic by having the powers of their surfaces excited by friction or incident light; but those bodies which do not thus eminently absorb or reflect light, and do not conduct electricity by their substance, are all in some degree phosphoretic.

That the light emitted from the phosphoretic body is not the identical light to which the body has been exposed, is proved by Mr. WILSON's experiments. It would therefore appear, that the species of the emitted light arises only from the particular disposition of the phosphoretic body, and that by being thus properly disposed, the same phosphoretic bodies may, after being excited, emit any one particular species of coloured light, according to the manner in which it had been disposed for this operation of producing light.

From

* Hutton's "Dissertations on different Subjects of Natural Philosophy."

From the experiments of Mr. Wilson it appears, that it is not the *exciting* light which is emitted by the body shining in the dark; it is not the *emitted* light, or light of the same species, which has the greatest power of exciting the *phosphorus* to shine; but the light which has so great an energy in exciting the phosphorus, is that species of light which is placed at the other extremity of the prismatic order, or most opposite in the rule of it's refrangibility from that of the emitted light.

Thus, though the incident light be a cause of shining by exciting this quality in the phosphoretic body, yet there is interposed another operation between the incidence and the emission of light; and there is reason to suppose, that the particular species of *light* emitted from the *phosphoretic* surface, depends on the *electric* fluid put in action by the incident light.

Phosphoretic and *phlogistic* bodies agree in containing a quantity of light, which is not in any perceived state of heat.

Although *phlogistic* and *phosphoretic* bodies emit light upon the same principles, so far as this depends upon luminous matter contained in the bodies, which is set at liberty during the operation, by which it is rendered luminous; yet the manner in which the luminous matter is set at liberty, is very different, as is that also by which the luminous matter is retained. The exposure to the atmosphere is essential to the emission of light from *phlogistic* bodies; but this is a circumstance indifferent or unnecessary for the same operation in those that are *phosphoretic*. In *phosphoretic* bodies there is no difference perceived after they have lost their shining qualities; but this is not the case with *phlogistic* bodies, where the greatest difference is perceived on the abstraction of their luminous matter.

Phosphoretic

Phosphoretic bodies furnish us with a strong additional proof of a principle already noticed, that *light* is matter which may continue for some time therein without exciting *heat*, and may be again separated therefrom, and resume it's character of light, as will appear by considering,

1st, That a phosphoretic body is made luminous only by it's having been exposed to light. 2dly, That it must be exposed to light of a certain intensity. 3dly, That provided the light falling upon the phosphoretic body be sufficiently intense, the most instantaneous exposition suffices to saturate the body, so as to make it emit light visible in the dark, equally as if it had been exposed thereto for a longer time.

It follows from hence, that *light* is matter, and that this solar substance may be retained in connection with a body, either upon it's surface, or connected with the gravitating matter of which the body consists.

GENERAL OBSERVATIONS CONCERNING SEVERAL OPERATIONS OF LIGHT IN RELATION TO BODIES. EXTRACTED FROM DR. HUTTON'S "DISSERTATIONS ON DIFFERENT SUBJECTS OF NATURAL PHILOSOPHY."

A body heated to an intense degree gives light, and light may be considered as matter moving in a strait course directed from a body. It is a matter of general observation, confirmed by the experiments of Mr. Pictet, that the intensity of heat in a body is diminished in proportion to the light which is emitted from the body.

Light emitted from a hot body, and meeting in it's course with a colder body, whose temperature may be accurately measured, may be either reflected from the surface of the opposing body, or extinguished within the substance of the body. In
this

this last case, if, in proportion to the light extinguished in the body, the intensity of heat be increased, it may be concluded, that fire is moved from the body in light, but the intensity of heat in a body is increased in proportion as light therein is extinguished; it therefore is, as to matter, the same with fire.

Heat and light may thus be considered as different modifications of the same matter, or different actions, according to the several conditions in which that matter may be placed.

Light, which is incident in relation to a body, may be either reflected or transmitted, or both, and that in greatest part. So far as light is reflected from the surface, or transmitted through the substance of a body, no heat should be excited in consequence of this modification of matter, which is not that of heat. This is consistent with observation, for no heat is excited by reflected or transmitted light.

By *fire* the volume of bodies may be *changed*, by *light* the figure of bodies may be *perceived*; but we know not whether fire and light have a proper bodily form; yet their existence is manifested by their effects; their actions, or laws of motion, are inferred or discerned by reason.

Nothing is more distinct than light and fire in their proper sensible qualities, but these sensible qualities are conditional. On the one hand, fire is not felt, if the sensitive body preserves it's natural or proper quantity of this substance; on the other hand, light is not perceived when falling on the skin or hands. As the conditions therefore necessary to the productions of those several sensations are perfectly different, from those different sensations we cannot conclude the matter employed in both is not the same.

Bodies in relation to light are either *luminous*.

or illuminated. It is only by means of light that bodies become visible, and this light must proceed from luminous bodies.

As bodies, by having the intensity of their heat sufficiently increased, may become luminous or made to emit light; if the light of bodies is considered in this most general view, the class of luminous bodies will be thereby greatly augmented.

In order to distinguish bodies that are *properly luminous* from those that *only emit light in consequence of heat*, it will be proper to observe, that bodies emitting light in this last manner, are not changed further than necessarily follows from the operation by which the proper degree of heat is produced; consequently these bodies may return to their former state, and, by being again heated, may have these operations repeated without limitation. But bodies properly luminous are limited in the quantity of light which they had retained, and which they are able to emit; after which those bodies, exhausted of their proper light, can only be luminous, in consequence of fire acting as heat.

Bodies that are eminently luminous must emit a quantity of light which had been contained in them; such bodies must therefore contain a certain species of matter in their substance, and this is called *phlogistic inflammable* or *combustible* matter. Now this phlogiston may in the chemical operations of matter be translated from the substance of one body to another; by which means bodies are made phlogistic, or capable of becoming eminently luminous, that were not so before.

All bodies that are made to give light require a certain degree of heat, without which they will remain without giving light; so that all bodies that are to emit light, whether properly luminous or not, agree in having the emission of light as a consequence

quence of heat, and in requiring a certain intensity of heat as a necessary condition for the emission of light: so far as this is the case, without heat bodies could not give light.

Heated bodies emitting light, I have already observed, are thereby continually losing heat, while colder bodies exposed to light, are receiving heat; such bodies therefore must have both their heat and light continually diminished, by forming an equilibrium of heat with contiguous and surrounding bodies.

It is otherwise with combustible bodies, for though these require a certain degree of heat as a condition of their emitting light; yet, as they also emit light upon other principles, so during their emission of light, appearances take place very different from those of bodies that are only luminous by the intensity of their heat.

The solar substance appears to be variously modified in relation to bodies, or differently disposed with regard to space and things; it is in one place *fire*, in another *light*, in a third *electricity*. In each of these modifications there are properly perceived actions with different intentions, but not opposite natures. From various similitudes, the several actions are concluded as belonging to the same kind of matter, from the separate purposes perceived in their various distinguished or different modifications.

Bodies, in relation to light, may be distinguished as of two different kinds; one kind giving light of their own, or which had been part of their substance, immediately before the act of emission; the other kind giving no light, except that with which they are illuminated from other bodies. Hence a general distinction of bodies, some being luminous, others dark or opaque.

Bodies, in relation to that light with which they

they are illuminated, are considered as of two kinds, either transparent or opaque. Here is therefore another sense, in which opacity may be taken; consequently, before the various affections of light and bodies are examined, it will be proper to have a distinct notion of this quality, which may perhaps be considered in different senses.

Opacity, as a quality in bodies, may be considered either in a more limited or in a more extensive sense; in the one case it signifies want of transparency, in the other that no light comes from a body. The first is a quality, properly or only opposed to transparency; the last will signify darkness in a body, from whatever cause.

Opacity being considered in the most extensive sense, then, as there are two different principles of lamination or modes by which light may proceed from a body, the quality of opacity may be examined in relation to each.

Light properly belonging to a body, being emitted, is said to come from a luminous body; therefore opacity in being applied to a body, may mean a body that emits no light of its own. But as, in this case, the light to be emitted is supposed to be part of the body, or its substance's opacity, in this particular sense, will mean a quality only in relation to the substance of the body, and not to its form, that is, to its figure and volume.

At the same time that this quality of opacity is thus found to be applicable only to the substance of a body, it must also appear that this is only a negative quality, meaning that the body has no light of its own to emit; or, if it does contain luminous matter, that there are not proper conditions for the emission of that substance.

With regard to the other mode of giving light, when a body may have opacity, or shall be considered as opaque, this relates to incident or foreign

foreign light. Light falling on a body may be either reflected, in which case it illuminates the body, or it may be transmitted; in which case the body is transparent; in neither of those two cases, is opacity, as a quality, necessarily perceived in that body. But light entering the surface of the body, and being there retained without immediate emission, here is to be perceived a quality in the body, which, at the same time that it is a positive quality, is also properly speaking the quality of opacity, as being opposed to the transmission of light, which is transparency.

In this case of opacity, considered as a positive quality, no relation is to be perceived between form, figure, or volume, the proper qualities of a body, and this quality or power in relation to light; therefore, opacity, in this most proper sense, must be considered as a quality, which, whilst it is positive, belongs only to the substance of the body, and may be properly examined without attending to the form or volume.

Transparency consisting in the free transmission of light through a body, the absolute solidity of the particles of matter in a body must be inconsistent with that quality; for, as transparent bodies transmit light equally in all directions, it is only by supposing the resisting parts of the body to be to the unresisting parts, in a ratio less than any assignable proportion, that this quality of perfect transparency can be thought consistent with the extension, and direct motion of the rays of light. At the same time, in judging from the hardness and incompressibility, if these are supposed to depend upon the solidity of the substance, there must be a great proportion of matter in the body.

But as there is no reason to doubt of the perfect transparency of bodies, considered solely as a transmitting quality, there is perhaps every reason

that can be drawn from the concurring testimony of natural appearances, to justify the supposition, that, in a transparent body, the absolute volume of matter, necessarily opposing the passage of light, and the absolute volume of the parts of light that must necessarily be opposed in passing through that body, are, to the rest of the space, in a ratio less than any assignable proportion. This being the case, it must be evident, that those two qualities of transparency in relation to the rays of light, and resisting power in relation to external force, are things plainly inconsistent, if we are to suppose solid matter to be the principal of bodies.

On the other hand, opacity, considered as a quality by which transmission through the substance of a body is refused, will appear not to arise from the necessary resistance of the matter in a body to the rays of light from it's extension, nor from the mechanical disposition of that matter in any conceivable manner; for, 1st, According to any way of forming a judgment, with regard to the quantity of matter in a body, that quantity does not appear to have any influence in producing opacity.

2dly, The smallest examinable quantity of matter, sufficiently opaque, appears to be as effectual to interrupt the passage of light, as the greatest quantity of matter not sufficiently opaque; at the same time this quality of opacity in a body, does not appear to be altered by any mechanical change or disposition of the parts: therefore, though the transparency of bodies were explicable from the supposition of infinite strength, and infinite rarity, in the solid matter and construction of bodies, this theory or supposition would still be inconsistent with the opposite quality, that is, opacity in bodies; for, while the greatest quantity of a dense transparent

parent substance transmits light perfectly in every possible direction, the smallest quantity of a rare opaque substance suffices to arrest light or retain it, without reflection or transmission. It is thus impossible, upon mechanical principles, to reconcile those two different qualities of bodies; therefore, independent of the insurmountable difficulty of constructing the solid matter of bodies for those two opposite purposes, here is a demonstration, from the simple quantities of the matter in bodies, by which it is proved, that opacity does not arise from any mechanical construction of solid matter; and therefore, that bodies are not composed of solid matter and space, separate and contiguous.

Light appears to pass through the substance of a homogeneous transparent body with equal facility, as it is conceived to move in the *rarest* or *voidest* space; consequently, the matter of such a body makes no sensible resistance to light. Therefore it may be inquired, what kind of matter is this, that has not the power of resisting light? Or, what particular powers in bodies are associated with this deficiency of power in relation to light?

The *hardest* and *softest* bodies are equally transparent; light does not appear to be transmitted through a *diamond* with less facility than through the *air*: therefore, that power in bodies, which resists the motion of the parts in relation to each other with so great intensity, does not resist the motion of light, or this particular modification of matter.

Fluid and *concreted* bodies, *water* and *crystal*, are equally transparent; consequently, that power by which the parts of bodies are directed to particular situations, does not interpose any resistance to the passage of light.

Heavy bodies may be transparent, as well as *lighter* bodies; *glass of lead*, *crystal*, *ice*, *air*, are all

transparent bodies; therefore, as the matter of light appears to have no gravitating power, the power of gravitation in bodies makes no opposition or resistance to the motion of light.

The *particular attractive powers* of substances appear to be no more disposed to resist the matter of light, than the general powers of bodies which have been considered; thus air, water, acid, alkali, and neutrals, are all transparent.

Therefore, from the examination of bodies with regard to transparency, this general conclusion may be formed, that the *attractive gravitating matter* in bodies appears to have no power calculated to oppose and resist light.

But in opaque bodies, there are powers by which light is effectually resisted.

In the transparent bodies already examined, every species of substance has been considered, except one; and this, which is *phlogistic* substance, not yet examined with regard to light, has been found capable of opposing, resisting, and changing every general attractive or gravitating power in bodies: therefore, on finding this substance properly adapted, whether in a mediate or immediate manner, for the opposition, resistance, and change of light, the qualities of transparency and opacity in bodies will be properly explained; at the same time that this natural appearance of transparent and opaque bodies being in perfect consistency with the theory of matter already investigated, will add that confirmation which in physical subjects is required.

Transparent bodies have been considered as not affecting the light, which thus traverses their substance with perfect facility; but it is a necessary condition for this purpose, that the substance be homogeneous, and equal in its density, or, that the body be sufficiently uniform in relation to the
volume

volume occupied by it's several parts; for a greater degree of density in one part of a body, otherwise perfectly homogeneous, disposes the body to affect the light in that part where the change of density takes place.

Hence the surfaces of contiguous bodies, which are transparent, but of different densities, are observed to affect light in different ways, and according to a certain rule.

Thus reflection, refraction, and extinction, are affections of light by transparent bodies, the rule or laws of which, to the honour of philosophy, have been so well investigated.

From the particular laws observed in those cases, there is reason to conclude, that there are certain powers situated in a place corresponding to the surfaces of bodies, by which light, that otherwise would be unaffected, may be both deflected in it's course, and arrested in it's motion. But on considering electricity, there are found certain powers situated precisely in this place; and, as the matter of electricity, which is properly situated in this place, and that proper to phlogistic substance by which alone light has appeared to be affected, are of the same kind, being different modifications of the same species of matter, there is reason to conclude, that the powers by which light is affected at the surfaces of transparent bodies, are of the same nature with those by which, in opaque bodies, light is also found to be affected.

OF THE INFLECTIONS OF THE RAYS OF LIGHT
WHICH PASS IN THE VICINITIES OF BODIES.

THE experiments on this subject by Sir I. Newton were the last that he made, and are acknowledged by himself to be incomplete; those who have followed him in this delicate and important department of natural philosophy, have done little more than added some insulated facts to those observed by him. The law followed by the powers that inflect the light, and the limits of it's action, are yet unknown. One, however, of the general results from the experiments is, *that bodies act upon light at small distances by attraction and repulsion.*

If a beam of the sun's light be admitted into a darkened chamber, through a hole of the breadth of a forty-secondth part of an inch or thereabouts, the shadows of hairs, threads, pins, straws, &c. appear considerably larger than they would be if the light passed by them in strait lines. For example, a hair whose breadth was the 280th part of an inch being held in this light, at about 12 feet from the hole, cast a shadow, which at the distance of 4 inches from the hair was the 60th part of an inch broad, that is, above four times the breadth of the hair. And the effect is the same, though the density of the medium contiguous to the small body be altered, the shadow at like distances being equal, whether it was in the open air, or inclosed between two plates of wet glass, care being taken that the incidence and emergence of the ray was perpendicular to the glasses. The scratches on the surface, or veins in the glass, cast shadows broader than they ought to be, from the usual refraction

fraction which might arise from any action of the ambient medium.

Let x , *fig. 2, pl. 7*, be a hair placed in the beam; ADG , BEH , KNQ , LOR , rays of light passing by the sides of it, are bent at x , and falling upon the paper GQ , the two rays TI , VS , pass by the hair without being deflected; but all the rays between TI and VS are bent in passing by the hair, and turned aside from the shadow IS . The light passing nearest the hair, as at D and N , is most bent passing to G and Q ; those that are farther off, as at E and O , are less bent; and so on to TI and VS : consequently the action upon the rays of light is strongest at the least distances, and grows weaker and weaker as the distance of the ray passing by is increased.

The shadows of all bodies in this light are bordered with three parallel fringes of coloured light; the nearest to the shadow is the brightest, and the furthest very faint; the order of the colours, reckoning from the innermost, are violet, blue, green, yellow, red. On looking at the sun through a feather or black ribbon, held close to the eye, several fringes of colours will appear.

Let a beam of the sun's light be admitted through a hole $\frac{1}{4}$ of an inch broad; place a sheet of pasteboard, blacked on both sides, at about 3 feet from the hole; in the middle of the pasteboard let there be a hole $\frac{1}{4}$ of an inch square for the light to pass through; behind the pasteboard fasten the blade of a sharp knife, so as to stop part of the light going through the hole. The knife and pasteboard are to be parallel, and both to be at right angles to the beam. Let a part of the light, which passes by the knife edge, fall upon a white paper at about 3 feet distance, and there will be two streams of light shooting out both ways into the shadow, somewhat like the tails of comets.

These streams being very faint, it is necessary, in order to see them distinctly, to let the direct rays pass through a hole in the paper on a piece of black cloth; the light of the streams is then perceptible on the paper to the distance of 6 or 8 inches from the sun's direct light each way, and in all the progress from that direct light decreases gradually till it becomes insensible.

Placing another knife with it's edge very near and parallel to the first, if they be distant the 400th part of an inch, the stream of light passing between them will be divided, parting in the middle, leaving a dark shadow in the interval: as the edges approach, the shadow grows broader, and the stream narrower at the inner end: so that the light that is least bent goes to the inner end of the stream, and passes at the greatest distance from the edges. This distance is about the 800th part of an inch; when the shadow begins first, the light which passes at less distances is more bent, and goes to that side which is farthest from the direct light: a little before the shadows appear, the fringes commence on both sides, and as the knives approach they grow more distinct and larger, till upon contact of the knives, the whole light vanishes, leaving it's place to the shadow.

Admit a beam of the sun's light through a small hole, made by a pin, in a thin plate of lead, and place a prism at the hole to refract the light on the opposite wall. The shadows of all bodies held in the coloured light are bordered with fringes of the colour of that light in which they are held; in the red, they are red; in the blue, blue, &c. but the fringes in the red light, are the largest; those in the violet, least; the green, between both; and this at all distances from the small body.

So that the rays which made the fringes in the red light, passed by the hair at a greater distance

tance than those which made the violet fringes; consequently the hair in causing these fringes acted similarly upon the red rays, which were at a greater distance, as upon the violet at less distances; and by these actions disposed the red light into larger fringes, and the violet into smaller, &c. without changing the colour of the rays.

When a hair is held in a white beam of solar light, and casts a shadow which is bordered by three fringes of coloured light, these colours arise from the various inflections by which the rays are separated, and being separated produce each its own colour. In the last experiment, where the rays are separated before the light comes to the hair, the red or least refrangible rays were inflected at greater distances, and the violet or most refrangible rays at a less distance, making three violet fringes at a less distance, whilst the red makes three red fringes at a greater distance; the mean rays making 3 fringes of their proper colours at mean distances from the shadow of the hair. In the white light these various colours are separated by the various inflection of the rays, and their fringes appear all together; the innermost being contiguous, make one broad fringe, composed of all the colours in due order, the violet being next the shadow, and the red farthest off, and the rest in their places. In like manner the middlemost fringes constitute one broad fringe, of all their colours, and the outmost fringe compose another broad fringe like the rest; and these are the three fringes of coloured light with which the shadows of all bodies are bordered.

From these and some other experiments of the same tendency, it may be inferred that the rays of light are influenced by some power that turns them out of their direct road; and as this power bends the rays not into the shadow of the bodies from whence the influence is supposed to proceed,

proceed, but from the shadow, it has been considered as a repulsive power which is strongest at the least distance.

OF THE ACTION OF LIGHT ON BODIES, AND THAT
THE COLOUR OF PLANTS, &c. DEPENDS ON LIGHT.

You will often find, that philosophical knowledge makes quicker advances by reasoning upon known facts, than by discovering new ones, which, though they enlarge and add to the subjects we ought to reason upon, are apt by their novelty to surprise us into hasty undigested theories. We have a strange propensity to be looking either behind or before us for variety, instead of cultivating the fruitful spot we stand upon. I am led to make this and some of the following observations from the subject before us, which has been too much neglected by modern philosophers: we have treatises on light, as separated and divided by the prism; on heat, as measured by the thermometer; but none on that ocean of the solar fluid, in which all bodies are as it were immersed;* none upon the various influences of the sun, upon which the life and activity of all things in this natural world depend. They seem to have forgotten, that the processes continually carrying on in nature, on every side, are as much the instruments of knowledge, as the more refined apparatus of the experimental philosopher. Sense and experience acquaint us with the course and analogy of appearances or natural effects; thought, reason, intellect, introduce us into the knowledge of their causes.

To avoid the conjectural method of some former philosophers, those of the present day are continually labouring to accumulate unconnected facts; thinking every new form, or every new appearance,

* Young's Essay on the Power and Mechanism of Nature.

pearance, an important discovery; seldom endeavouring to trace out their connection with superior and inferior causes, on which all their real powers and activities depend. If we stop at experiments, without proceeding any further, we shall never arrive at any causes; and if we rely wholly upon experiment, we shall come at none but false ones; because the principal agent in nature is so subtil as to elude both sense and experiment, so that they can never discover it, though when we have been told of it they will serve to demonstrate it's observations.

The ancients paid little attention to experimental philosophy, but devoted themselves, with a truly philosophical ardour, to the observation of the phenomena of nature; and that process was consonant to sound reason, for experiment is only properly called in to fill up the chasm which simple observation necessarily leaves.

The department of experimental philosophy is the unfolding of those phenomena, whose causes cannot be discovered by unassisted reason, and whose connection it cannot trace; the advancement therefore of this branch of science depends on the number and accuracy of our observations with respect to the relations which natural objects have to each other.

It has been well observed by Dr. G. Fordyce,* that "all our knowledge of every thing whatever must arise from experiment only, that is, from the evidence our senses give us of what appearances nature, in other words, the creatures of the Almighty, give impressions of." Yet "some of these impressions are received from the ideas that arise from things not at all under our dominion, or from circumstances more immediately governed by the Almighty. Thus, for example, a man sees a tree lose it's leaves in autumn, sees them renewed
in

* Fordyce on the Digestion of Food,

in spring, and a new growth takes place during the summer; he sees the blossoms open in the spring; these he finds followed by the fruit, which, if it falls into the earth, is capable of producing new trees of the same species; or he sees it gathered by animals, and affording nourishment. In this *mode* of acquiring knowledge man is totally *passive*; he did not contrive to make leaves fall in the autumn, and be reproduced in spring; he did not contrive to make new wood grow in the summer, nor that blossoms should open, that the seeds should be impregnated with the embryo; he did not contrive that the fruit should grow, nor did he teach animals that it was fit for their nourishment. What knowledge is acquired by attention to these natural circumstances, has been called *observation*. It is indeed a contemplation of the *benevolence* of the ALMIGHTY, giving nourishment and happiness to all the inhabitants of the earth.

“The minds of mankind, not satisfied with their powers of observation of what passes in this earth, but being even forced for their own subsistence to exert themselves far beyond the brute creation, are necessarily led to make a farther inquiry, and that with a labour beyond the contemplation of the benevolence of the Almighty. To those creatures who have only this earth to exist in, food and raiment are afforded, without labour or attention, during the short period of their lives. It is not sufficient for the farmer to look where grain grows naturally; it is necessary to try, with an infinite variety of applications that may be made to the ground, to produce crops superior to those which would arise in it without any cultivation. It is necessary for the hunter not only to observe the natural history of wild beasts, but also to try by what means he can engage them to fall into his toils. It is necessary for the fisherman, besides

admiring the multiplicity of fish, to be able to contrive either to entangle or surprise them into his nets. In many other cases it is necessary for mankind not only to contemplate those things which happen naturally, but he is likewise constrained to form projects of his own, and to contrive means of putting both mind and matter in circumstances foreign to what would naturally arise in them, and contemplate the effects; and this we call experiment.

"Thus observation and experiment are the sources of all the knowledge of mankind.

"Man seems to have a degree of pride planted in his nature, which prompts him constantly to consider himself as being far superior to what he actually is, which instinct is the surest proof that *he is to be very superior indeed.** But as all the virtues of man are ballanced by opposite imperfections, the pride of experiment has often thrown science into confusion, instead of advancing it's progress. An experiment to prove a thing otherwise demonstrable is totally superfluous, and not only superfluous but fallacious."

Another circumstance which injures philosophical pursuits, and retards their progress, is the neglect of old principles as soon as new ones are assumed, as if their efficiency ceased immediately, like that of old ministers of state upon the introducing of new ones. If the placita of their predecessors were not lost sight of or neglected, they would sooner attain the end of their inquiries, than by
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* Every vanity of man shews his degraded state, and from what dignity he has fallen. Did not man find and feel that he is a poor prisoner in the valley and shadow of death, he would no more have any of those instincts alluded to above, nor any reaching desire after all the beauties of fallen nature, than the ox to have his pasture inclosed with beautiful walls and painted gates.

being so intent on their own discoveries as to neglect, as rubbish, all those circumstances that were formerly of such moment.

That light and fire are substantially the same, or different modifications of the same fluid, is evident from their commutability, or their reciprocal generation of each other. For as fire necessarily generates light, and thus discovers itself to the sense of seeing as infallibly as to the feeling; so light conveyed to a focus, constitutes pure fire. Light and heat are propagated by the same laws; they act in strait lines; they diffuse themselves from a center outward; their powers decay according to their distances from the centers from which they are irradiated; they are subject to the same laws of reflection.

Notwithstanding that the phenomena of nature, which tend to ascertain beyond doubt that the matter of common light or fire pervades all nature and fills all things, are exceeding numerous and obvious to every eye; yet the whole has been overlooked as an accidental filtration, implying no consequences, nor interfering with the various properties of bodies, notwithstanding it's access to their innermost penetralia.

Our globe itself seems to be nothing more than an accumulation of terrestrial materials, introduced into the boundless ocean of the solar fluid, for a theatre on which it may display it's inexhaustible power and energy; the mass being so disposed and arranged by it's author as to become a seminal bed of materials, to be pierced and animated by *light*, and from which materials light can extricate all the forms, and generate all the powers in nature.

Without this principle all that we call body would remain for ever an inactive, passive, incoherent calx. Water by it's transparency evidences to your senses, that light has free access into and

through it's substance. By the volatilization of water it is equally evident, that light or fire has not only access to it's interstices, but penetrates and occupies it's similar elementary particles, in the conformation of which particles the character of water consists. These particles could not be rendered volatile but by internal dilatation, nor could they be dilated but by something that reached their internal parts ; they have their individuality as separable elementary particles, as well as their similarity of character preserved by the ætherial principle possessing them. If the natural life of all things depends on the activity communicated to them by the sun, is it not evident that it is the same influence which must generate and maintain that life in all it's specific characters, in every being according to it's kind ?

When the *sun* is said to *rule* over the day, and to have been made for this end, what else can be understood but that he acts as a vicegerent ; and is invested with a mechanical power of giving light, life, and motion, to such objects as are ordained to receive his impressions ? All nature revives, and puts on a new face, when he approaches us in spring ; and sinks into a temporary death, at his departure from us in the winter. That he acts in a mechanical manner, is also certain, because a chain of matter is continued all the way from the agent to the object. His power consists not in any immaterial quality, because it observes the same geometrical law with the diffusion of it's light ; and his efficacy upon the production of the earth is greatest, when the greatest angle is formed between the horizon and his *rays*. A good telescope will shew you what changes are produced in the refraction of the atmosphere, and what a tumult arises in the air from the agitation of the sunbeams in the heat of noon-day ; the heaven seems transparent

transparent and undisturbed to the naked eye, while a storm is raised in the air by the impulse of light, not unlike what is raised in the waters of the sea by the impetuosity of the wind. It increases with the altitude of the sun; and when the evening comes on, it subsides almost into a calm.*

Light is now no longer considered by chemists,† merely as an ideal substance; they perceive it's influence in many of their operations, and as it modifies many of their results, they find it necessary to attend to it's action.

The effects of light are more evident in the phenomena of nature, than in the experiments performed in the laboratory.

Light is absolutely necessary to plants; vegetation does not succeed without it; deprived of this principle, they become pale, languish, and die. It appears from incontestible facts, that the root of the most variegated flower, though excluded from the external air under a glass vessel, will, provided it be daily exposed to the light of the sun, arrive at it's utmost perfection both with respect to fragrance and colour; but if the process be reversed, and the air admitted without the light, the flower may perhaps grow to it's natural size, but we shall in vain look for that beautiful variety of vivid colouring, and that exquisite perfume which nature bestows on every individual of the species, when permitted to imbibe and enjoy the solar beam.

The same fact is further evinced by a variety of experiments by several French academicians, in which the light was admitted to one part of a plant, and excluded from the others. The invariable effect of this was, that the part exposed to the

* Chaptal's Elements of Chemistry.

† Jones's Essay on the First Principles of Philosophy.
— Physiological Disquisitions.

the sun was of a lively green, while that which was shaded continued of a disagreeable pale colour; nay, so powerful are the effects of the sun's light on vegetables, that when deprived of it, their taste and other native properties undergo such a change, that some, in their nature poisonous, become a safe and wholesome food. Without the influence of light, vegetables would exhibit one lifeless colour, and are deprived of their beautiful shades by the interception of the luminary fluid. On these principles, celery, endive, and other plants, are *bleached*.

All these circumstances evidently shew, that there is something in light absolutely necessary to vegetable life. Hence all plants shew a remarkable sensibility to the light; they expand their leaves, and open their flowers to the sun, and close them the moment he disappears. Many accurate experiments prove, that it is not the heat but the light of the sun, that causes them to turn to him. A plant in a room, where there is a fire, turns it's flowers to the light which comes from the colder side.

Many experiments shew, that the change of position in the leaves of plants, at different periods of the day and night, is entirely owing to the agency of light. The upper surface of leaves, which are supposed to be their organ of respiration, seems to require *light* as well as *air*; for plants, which grow in windows on the inside of houses, are as it were solicitous to turn the upper sides of their leaves to the light. This agent is subtil, active, and penetrating; by the smallness of it's constituent particles, it is capable of entering all bodies, and from it's activity of producing great effects and considerable changes therein.

Vegetables are not only indebted to the light for their colours, but likewise for their smell, taste,

combustibility, maturity, and the resinous principle, which equally depend upon this fluid.* The aromatic substances, resins, and volatile oil, are the inheritance of southern climates, where the light is more pure, constant, and intense. All these circumstances, it is hoped, will concur to make you attentive to the nature and office of the *sun*. The sun is *the united power* of fire and light, and by these powers calls forth from the earth a beautiful variety of vegetable life, cloathing them with it's own brightness and beauty, and rendering them holders and displayers of all it's colours, powers, and virtues.

The influence of light is evident on other animated beings : worms and grubs, which live in the earth or in wood, are of a whitish colour. Birds, and flying insects of the night, are likewise distinguishable from those of the day by the want of brilliancy in colouring; and the difference is still more marked between those of the north and of the south.

A very astonishing property of light upon the vegetable kingdom is, that when vegetables are exposed to open day-light, or to the sun's rays, they emit vital air.†

It has been proved, that the sun does not act in the production of this phenomenon as a body which heats. The emission of the air is determined by the light; pure air is therefore separated by the action of light, and the operation is stronger as the light is more vivid. It would seem that light favours the work of digestion in the plant, and that the vital air which is one of the principles of almost all the nutritive juices, more especially of water, is emitted when it finds no substance

* Chaptal's Elements of Chemistry.

† Lecture x.

substance to combine with it in the vegetable. Hence plants, whose vegetation is the most vigorous, afford the greatest quantity of air.

By this continual emission of vital air, the Author of nature incessantly repairs the loss thereof occasioned by respiration, combustion, and the alteration of bodies, including every kind of fermentation and putrification: in this manner the equilibrium is always maintained between the constituent parts of the atmosphere.

Scheele and Berthollet have shewn, that the absence or presence of light has an astonishing effect upon the result of chemical experiments. Light disengages vital air from several fluids, such as the nitrous acid, dephlogisticated marine acid, &c.; it reduces the calces of gold, silver, &c.; it changes, according to Mr. Berthollet, the nature of oxygenated muriates. M. Chaptal has shewn, that it determines the phenomena of vegetation, exhibited by saline solutions. These circumstances shew the importance of light, and how much it's agency in nature should be attended to by every philosopher: *heat* often accompanies light, but some of the phenomena, we have mentioned, cannot be attributed to mere heat; heat may indeed modify them where it exists, but is not the producing cause.

There are many instances where the action of the solar light contributes to the destruction of colour, and instead of extricating vital air, fixes it, and produces a kind of combustion. In like manner phosphorus, while in the dark, is not affected by the oxygenated muriatic acid, even assisted by heat; but when the action of light concurs, it is converted into phosphoric acid.*

A variety of facts shew, that vital air is capable

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* Berthollet's Art of Dyeing:

ble of whitening or rendering paler the colouring matter with which it unites, perhaps by having produced on them the effects of a slight combustion.* Vital air has considerable influence on the colouring particles of vegetables; these are formed chiefly in the leaves, flowers, and inner bark of trees, and by degrees they undergo a slight combustion: hence most trees contain fawn-coloured particles.

The manner in which the sun acts upon colours may be seen by examining the appearances presented by a solution of the green part of vegetables in alcohol.

If such a solution, which is of a fine green colour, be exposed to the light of the sun, it very soon acquires an olive hue, and loses its colour in a few minutes. If the light be weak, the effect is slower; and in perfect darkness the colour remains without alteration, or requires a great length of time.

M. Berthollet inverted over mercury a bottle half full of this green solution; when the colour was discharged, the mercury was found to have risen in the bottle, and consequently vital air had been absorbed, the air having united with the colouring matter; on evaporating this liquor, its colour was immediately rendered darker, and became brown: the residuum was black, and in the state of charcoal.

The light seemed therefore to have produced its effect by favouring the absorption of vital air, and the combustion of the colouring matter; the marks of combustion are not evident at first, but by the assistance of heat the liquor becomes brown, and leaves a black residuum. If the vessel containing the liquor holds no vital air, the light has no effect on the colouring matter.

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* See what was said on incipient ignition, under the article of phosphori.

The effects of light on the colour of wood have been long observed; it preserves it's natural appearance while kept in the dark, but when exposed to the light it becomes yellow, brown, or of other shades. M. Senebier found, that the changes were proportioned to the brightness of the light, that several folds of ribbon were required to defend the wood completely, that a single leaf of black paper was sufficient; but that when paper of any other colour was substituted, the change was not prevented; a single covering of white paper was insufficient, but two intercepted the action of the light. These observations are important, as they prove that light can pass through coverings that appear to be opaque, and exerts it's energy at some distance within.

M. Berthollet put tincture of turnsole in contact with vital air over mercury; one parcel he placed in the dark, the other was exposed to the light of the sun; the former continued unchanged for a considerable length of time, and the vital air was not diminished; the other lost much of it's colour, became red, and the air was in a great measure absorbed, and a small quantity of fixed air was produced, which no doubt had occasioned the change of colour from blue to red.

This observation may lead us to form an idea of some of the changes produced by a particular disposition of the component parts of vegetable substances, when by the combination of vital air they undergo the effects of a slight combustion, which may generate an acid; as in the leaves in autumn, which grow red before they become yellow, and in the streaks observable in flowers, whose vegetation is growing languid.

The success of the present age in arts, experiments, and new systems, is very apt to elate the minds of men, and make them overlook the an-

cients. But notwithstanding the encouragement and purse of princes, and the united endeavours of great societies in these later ages, have extended experimental and mechanical knowledge; yet it must be owned, the ancients were not ignorant of many things, which are now more generally, though not first known. Their notions of fire and light, the result of observation, were for the most part just. They considered the principles of motion and vegetation as delibations from the invisible fire of the universe, which, though present to all things, is not nevertheless one way received by all; but variously imbibed, attracted, and secreted by the fine capillaries and exquisite strainers in the bodies of plants and animals, and is thereby mixed and detained in their juices. They supposed the elaborate spirit, whereon the character, distinguishing virtue, and properties of the plant depend, to be of a luminous and volatile nature.

It was from an ethereal and luminous fluid that they derived the many and various qualities, virtues, odours, flavours, and colours, which distinguish natural productions; conceiving that the original particles productive of these properties were diversely separated, and attracted by the various subjects of the animal, vegetable, and mineral kingdoms, which thereby become classed into kinds; and indeed with those distinct properties which continued till their several forms, or specific proportions of fire, returned into the common mass.

They considered all the appearances of fire, even in earthly things, as something of a heavenly, exalting, and glorious nature; as that which disperses *death*, *darkness*, and *grossness*, and raises up the power and glory of every *life*; that it was seldom seen in this world but as a *destroyer*, a *consumer*, and *refiner* of *grossness*; as a *kindler* of life and
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light out of death and darkness ; that so much as any thing had of light, so much it had of heaven ; and that this was rendered evident in the power of the sun, and manifested in the *softness* of sounds, the *beauty* of colours, the *fragrance* of smells, and the *richness* of taste.

Before I finish this Lecture, I must make a further observation on colour, on account of the mischievous inferences deduced from the Newtonian theory, by Voltaire and some other infidel writers. These men suppose that light and colour, as apprehended by the imagination, are only ideas in the mind, and not qualities that have any existence in matter. Strange as this may seem, it has been universally received, and considered by some as one of the noblest discoveries of modern philosophy.

By colours all men, who have not been tutored in this school, understand not a sensation of the mind, which can have no existence when it is not perceived, but a quality and modification of bodies, which continues the same whether it be seen or not. The scarlet rose, which is before me, is still a scarlet rose when I shut my eyes, and was so at midnight when no eye saw it ; the colour remains when the appearance ceases ; it remains the same when the appearance changes ; for when I view this scarlet rose, through a pair of green spectacles, the appearance is changed ; but I do not conceive the colour in the rose to be changed. To a person in a jaundice it has still another appearance, but he is easily convinced the change is in his eye, not in the colour of the object. We can by a variety of optical experiments change the appearance of figure and magnitude in a body, as well as that of colour ; we can make one body appear to be ten. But no man believes the multiplying glass really produces ten guineas out of one ; in like manner, no one believes the coloured glass changes the
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real colour of the object seen through it, when it alters the appearance of that colour.

Colour is not a sensation, but a secondary quality of bodies, whereby in fair day-light they exhibit a certain and well understood appearance; and there is a real permanent quality in bodies, to which the common use of this word agrees. Had modern philosophers given, as they ought to have done, the name of colour to the *cause* instead of to the effect, they would not have set philosophy apparently in contradiction with common sense; for they must then have affirmed with the vulgar, that colour is a property of bodies, and that there is nothing like it in the mind. Their language as well as their sentiments would have been perfectly agreeable to the common apprehensions of mankind, and true philosophy would have joined hands with common sense.*

Instead of seeking objections against revelation from every appearance in nature, the true philosopher finds abundant ground therein to confirm and establish his faith; he learns from the adaptation of objects to the senses, the absurdity of those infidels, and their want of knowledge in the human understanding, who require for conviction a stronger evidence in the objects of faith, than is to be offered for those of the other faculties.

In examining the objects of various parts of intellect, do not we find men at a loss to prove in what manner they exist? Do they suspend their assent to the reality of a rose, till they can explain why the leaves are of a different colour, odour, and shape, from those of the lily? or why they are of any particular smell, shape, or colour? Is it an objection to the evidence of the eye-sight, that the sounds of a violin are imperceptible by that organ?

* Reid's Inquiry into the Human Mind.

or because neither form nor found are the objects of reason, that neither of them exists? Would not a geometrician treat with contempt the person who should deny the reality of the properties of a square, because they are irreconcilable with those of a circle? All that is required in these instances, is a consentaneous disposition in the objects and the faculties to impart and receive those ideas, and the mind rests convinced of their realities.

The utility and pleasure which are derived from the senses are the great proofs which satisfy men of the reality of the *objects* of them. He whose eye-sight prevents him from running over a precipice, whose ears are delighted with the powers of harmony, can entertain no doubt of the existence of those objects; and whoever should attempt to prove that the first was not seen, and the latter not heard, would inevitably render himself an object of ridicule. And is not a man equally ridiculous, who denies that the objects of faith are real, though he is every day acquiring happiness, and obtaining security, as the result of them? The adaptation of the doctrines of faith to the nature of man, and the superior utility arising from it, are the strongest proofs of its divine original; their principles correspond to the faculties and wants of human nature, and its precepts to their welfare.

To deny these proofs would be to reject all moral evidence, and even the existence of a *Deity*. When we perceive all parts of matter fitted to the uses of creation; when we see that rain and sun are necessary to vegetation, and that the order and course thereof is such, that they never fail the purposes of their intentions; is it possible to deny the *providence* of a *supreme* intelligence? In like manner, when it is discovered that all parts of our religion coincide as perfectly with the nature of man

man and his welfare, is it not equally absurd to reject it as proceeding from the same source?

Whoever consults the sensations of his own mind, will feel the evidence of the hereditary evil of man as evincing, as the dry leaf is expressive of it's having been in a more perfect state. What are the presentiments and presages of the soul, but the remains of a more perfect intelligence? And what is that abatement of pleasure which enjoyment tastes, compared with the felicity imagination preconceives, but an indication of the defect in human faculties? Like the evanescent colours of a declining tulip, they pronounce their former excellence.

The sense of degradation, and of it's being irremediable by the powers of man, creates those desires in the human breast which are constantly yearning after a better state, and the belief of the necessity of a more perfect being to restore it. Here the idea of infinite mercy, inseparable from the Divine Being, leads the soul to see that it's redemption can only be accomplished by the Supreme Being. Thus you may perceive, that the truths of christianity are obvious and plain; they speak the language of nature; and all nature is expressive of the sense and sound thereof; and points out the necessity of a REDEEMER, whose existence and influence is as extensive as nature itself.

To shew that nothing under him, "in whom we live, and move, and have our being," could redeem us, our REDEEMER, when he had shrouded his BEAUTY with the veil of mortality, gave hourly and ocular proofs of his GODHEAD by the extent of his power in and over all things. "In HIS WORD was LIFE, in HIS BREATH was healing, and sickness grew sound at HIS sight; the lame sprang up at HIS bidding, by HIM the deaf ear was opened, and the dumb tongue loosed to utterance; HE poured
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the beams of his light upon the new opening eyes of the blind-born gazer; death fled before HIM, and amidst the tombs HIS WORD was *life* and *resurrection*; the *tempest* heard HIS voice and was still; the *earth* trembled with reverence; and the *sea* spread itself as a carpet beneath the foot of her CREATOR.

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- “ Even all his mighty works to me import,
- “ But as they greatly serve to authorize
- “ The mightier words he uttered—as the eye
- “ Bears witness to the light, or the charm’d ear
- “ To tuneful undulation; so the heart
- “ Strikes unison to his great law of LOVE,
- “ And proves his mission all DIVINE.”

LECTURE XXII.

ON TELESCOPES.

IN our last Lectures, I endeavoured to render plain and easy to your comprehension, some of the great discoveries of Sir ISAAC NEWTON, who surpassed himself in his *Theory of Light and Colours*, as much as he had exceeded others in his *Principia*. Both these works give testimony to the depth and clearness of his intellect, his skill in conducting experiments, and the comprehensive force of his mind. But far as he has penetrated into the recesses of light, the same Lectures must have convinced you, that many appearances are yet unexplained, many difficulties are yet unexplored; and that the instances are numerous which prove, that the inward constitution, the real causes, and connections of the most obvious phenomena, are beyond your apprehension.

Vanity in any man is weakness; but a vain philosopher is the most absurd among men, for every new discovery demonstrates his imbecility; every new effect that is brought to light, serves only to convince him of innumerable others which remain concealed, and of which he had no previous knowledge: the works of God are too vast, and of too large an extent for our capacities. There is such an expanse of power, wisdom, and goodness, in the formation of the world, as is too mighty for our grasp, too much for us to comprehend. Power, wisdom, and goodness, are manifest to us in all those works of God which are within our view: but there are likewise infinite stores of each poured forth

forth throughout the immensity of the creation, no part of which can be understood without taking in it's reference and respect to the whole, and this is beyond the reach of human faculties. *To whom hath the root of wisdom been revealed? or who hath known her wise counsels? There is one wise and greatly to be feared, the LORD sitting upon his throne. He created her, and saw her, and numbered her, and poured her out upon all his works.*

These reflections naturally occur to the mind when it contemplates the discovery of the telescope, and the advantage arising from it; for who, reasoning *a priori*, could have imagined that the refraction of light in glass, the same power by which a strait rod appears crooked in water, whereby vision is variously distorted, and whereby we are liable to innumerable deceptions, should ever be so circumstanced as to extend the boundaries of sight, and enable us to distinguish objects too remote for natural vision? Yet such are the powers science has bestowed, that by glasses, properly adapted to each other, we as it were contract space, and bring within our ken the grander objects of the universe; and are enabled to extend our inquiries beyond the boundaries of the solar system.

If Pliny, in regard to *Hipparchus*, could extravagantly say, "*Aufus rem, Deo improbam annumerare posteris stellas,*" what would that pompous historian of nature have said, had it been foretold him, that in the latter days a man would arise, who should enable posterity to enumerate more new stars, than *Hipparchus* had counted of the old; who should assign four moons to Jupiter, and in our moon point out higher mountains than any here below; who should in the sun, the fountain of light, discover dark spots as broad as two quarters of the earth, and by these spots ascertain

his motion round his axis; who, by the varying phases of the planets, should compose the shortest and plainest demonstration of the solar system? Yet these were but part of the annunciations to the world of a single person, of *Galileo*, of unperishing memory! To him, his cotemporary and rival in fame, *Lord Bacon*, ascribed the invention of *perspicilla*, (for so at first were called the telescopes,) and in a figurative strain thus expressed himself concerning them: "With these (*perspicilla*), which *Galileo*, by a memorable effort of genius, hath discovered, we are enabled, as with some small sailing vessels, to open and keep up a nearer commerce with the stars."

Nor did the celestial commerce cease with the acquisitions of *Galileo*, but has been extending ever since the time that that great man first turned his glasses to the heavens.* In our own day the energy and philosophic enthusiasm of *Herschell* has enlarged the boundaries of astronomical knowledge, added a new planet to our system; the heavens have, as it were, increased under his eye; and 44000 stars, seen in the space of a few degrees, seem to indicate that seventy-five millions may be discovered in the expanse exposed to human investigation.

What is necessary for the conduct of our animal life, the bountiful AUTHOR of nature has made manifest to all men. But there are many other choice secrets of nature, the discovery of which enlarges the power and exalts the state of man; these are left to be discovered by the use of our rational powers; they are hid, not that they may be always concealed from human knowledge, but that we may be excited to search for them: this is the proper business of a philosopher; and it is the glory of a man,
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* Sir John Pringle's Discourses, p. 228.

and a reward for his labour, to discover that which has been thus concealed.

Thus in the subject before us, our eyes are incapable of discerning objects, either very small or very distant; but the CREATOR has given properties and qualities to matter by which it may procure us these advantages: HE elevated the understanding from one degree of knowledge to another, till it was able to discover these assistances for our sight. It is to the same power, therefore, who created the objects of our admiration, that we are ultimately to refer the means of their discovery; and whatever we find out by their means, becomes a fresh source of praise to HIM from whom we receive every blessing.

The very great importance of the telescope has made the first discovery of it an interesting object of inquiry; but no research has been able to ascertain either the exact period when it was first found out, or who was the inventor. It has been by some, and with no small degree of probability, attributed to the famous friar, Roger Bacon, before the year 1300, and it is worth your while to be acquainted with some of his expressions. *Lenses and specula may be so figured, that one object may be multiplied into many; that those which are situated at a great distance may be made to appear very near; that those which are small may be made to appear very large, and those which are obscure very plain; and we can make stars to appear wherever we will.* These and other expressions and tracts of this author seem to indicate, that he was well acquainted with the nature, construction, and use of telescopes, and all the glasses which compose them; but some modern critics in the science not only deny him the invention, but even the knowledge of any such construction, as we at present call telescopes, though he mentions the refractions of the sun's rays

rays through a glass sphere; but as he does not say, *totidem verbis*, that he ever viewed an object through such a sphere, Dr. Smith supposes that he had no experience of it's magnifying power. In the same manner, had *Seneca* described his glass ball, filled with water, only as a burning-glass, it might have tempted us to argue that he knew nothing of it's use in *magnifying letters*; but he has precluded conjecture by declaring the contrary. He might know more than is spoken of; the mathematicians and workers in glass of those days might know more than he did. From the foregoing and other expressions of our countryman, *Friar Bacon*, there is little doubt but that he was acquainted both with spectacles and telescopes.

"*Friar Bacon*," says the Rev. Mr. William Jones, "may be considered as the first of English philosophers; his profound skill in mechanics, optics, astronomy, and chemistry, would make an honourable figure in the present age; but he is entitled to further praise, as he made all his studies subservient to theology, and directed all his writings, as much as could be, to the glory of God. He had the highest regard for the sacred scriptures, and was persuaded they contain the principles of all true science. He had a liberal way of considering things, not adhering servilely to his subject, but using all the sciences of which he was master to illustrate each other. It is very unjust to speak of philosophy, as if it was unknown till the last century, when in reality a scholar furnished with no materials, but such as might be extracted from *Friar Bacon's* works, would yet be a very considerable person, and entitled to no small degree of

* Jones's *Physiological Disquisitions*, Introduction.
Duten's *Inquiry into the Origin of Modern Discoveries*.
Biographia Britannica.

of fame among the literati of the present age. He would excel as a mathematician, experimentalist, physician, chemist, artist, astronomer, philosopher, and divine."

Men of learning have been divided in their opinions concerning the optical knowledge of the ancients; some are so swallowed up by an admiration of the discoveries that have been made in the last and present century, that they have been tempted to pass sentence upon the ancients, before they knew what the ancients have said for themselves. It is said, indeed, that if dioptric glasses were anciently in use, it is strange we find them so seldom mentioned in their writings. This may be hard to account for, but it is unsafe to draw a positive conclusion from negative evidence. The accounts we have of many ancient works of art are so much broken by the injuries of time, the ambiguities of language, the succeeding interests of different sects of philosophers, the barbarism of succeeding ages, that it is now very difficult to establish the supposition by satisfactory proofs.

If we argue by *inference*, the case will be a little altered. The cabinets of the curious contain some very ancient gems, of admirable workmanship, the figures on which are so small, that they appear beautiful through a magnifying glass, but altogether confused and indistinct to the naked eye: and if they cannot be viewed, how could they be wrought without the assistance of glasses? How could it be known that the moon has a form like that of the earth; that it has plains, hills, and valleys in it? When it is seen through a telescope, the disposition of light and shade render this evident, agreeable to the common rules of perspective; but no such thing appears to the naked eye. How could it be known that the *via lactea* arises from the combined rays of an infinite number of small stars?

stars? But above all, how came it to be asserted, that the sphere of the fixed stars is so immense, that the circle of the earth's annual orb bears no greater proportion to it than the center of any sphere bears to it's whole surface? This discovery does so far exceed the comprehension of the human mind, that it was not asserted after the revival of the Pythagorean scheme, till Dr. Bradley, by a course of the most accurate observations that ever were made with a telescopic apparatus, reduced the annual parallax of the fixed stars to an insensible quantity.

If leaving the ancients we return to the moderns, we find the time of the invention, and the name of the inventor, are still involved in obscurity. By some it is ascribed to James Mœtius, a Dutchman; by others to John Leppersheim, of Middleburg: but Borellus, in a circumstantial and apparently well authenticated account, attributes the invention to Zacharias Jansen, of Middleburg, about the year 1590. Jansen was a diligent inquirer into nature, and being engaged in these pursuits, and trying what advantages could be derived from combining lenses, fortunately discovered the telescope.

The wonderful effects of this instrument soon reached Galileo, who, setting himself to work, contrived an instrument to effect the same purpose. As this subject is so curious and interesting, I think you will be pleased with his own account of it, as published in a book intitled, *Nuncius Siderius*, in March, 1610. "Near ten months ago," says he, "it was reported that a certain Dutchman had made a perspective, through which many distant objects appeared as distinct as if they were near; several effects of this wonderful instrument were reported, which some believed, and others denied: but having had it confirmed to me a few days after by a letter from the noble John Badoverie,

Badoverie, at Paris, I applied myself to consider the rationale thereof, and by what means I might contrive a similar instrument, which I afterwards attained to by the doctrine of refraction; and first I prepared a leaden tube, to whose extremity I fitted two spectacle-glasses, both of them plain on one side; on the other one of them was spherically convex, and the other concave. I saw objects appear pretty large, and pretty near; they appeared three times nearer, and nine times larger in surface than to the naked eye: and soon after I made another, which represented objects above 60 times larger; and at last, having spared no labour or expence, I made an instrument so excellent as to shew things almost a thousand times larger, and above thirty times nearer than to the naked eye."

If the true inventor is he who makes discovery by reasoning *a priori*, and descending from established principles to their consequences, Galileo may be considered as the real inventor of the telescope; but the use he made of it does him more honour than the invention: the instrument was at first, in Holland, a mere article of curiosity, not an instrument of science; himself being amply rewarded by prevailing over the difficulty of the subject, and with new discoveries which enlarged the territories of reason.

OF REFRACTING TELESCOPES.

By a *telescope* is usually signified an instrument that renders the view of distant objects more perfect; or, in more general terms, which represents distant objects under a larger angle than that under which they appear to the naked eye.

When the distance of the object is very considerable, the effects may all be referred to the same distance, and a telescope may be said to enlarge an

object just as many times as the angle under which it represents it is greater than that under which it appears to the naked eye. Thus the moon appears to the naked eye under an angle of about half a degree; consequently a telescope magnifies 100 times, if it represents the moon under an angle of 50 degrees; if it magnified 200 times, it would exhibit the moon under an angle of 100 degrees; and the moon would appear to occupy more than half the visible heavens, of which the whole extent is only 180 degrees.

It is a common expression, that telescopes bring objects nearer; but this expression is equivocal, admitting of two different significations. The one is, that, looking through a telescope, we estimate an object to be as much nearer to us as it is magnified by the telescope. But I have already shewn you, that we can form no certain estimate of the distance of an object but by the judgment, and that our judgment deceives us when the objects are beyond a certain distance; and in the present instance, losing all those subjects of comparison on which it is founded, will deceive us more. The other meaning applied to the expression is, that the telescope represents the objects as large as they would appear if we were so much nearer to them: this latter meaning is more conformable to the truth than the preceding, for you know that the nearer we approach to an object the larger is the visual angle. When you look, however, at a well known object, as a man, at a great distance, and he is seen under a larger angle, we are led to think him so much nearer, when he would really appear under a greater angle; but with respect to objects less known, as the sun and moon, there can be no estimation of distance.

One principal end of telescopes is to enlarge or multiply the angle under which objects appear

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to the naked eye, and they are estimated according to this effect, and are said to magnify five, ten, or any other number of times, according to the nature and construction of the telescope.

This diagram, *fig. 13, pl. 6*, represents a small Galilean telescope: the convex lens *P, P*, is directed toward the object, the concave glass *Q, Q*, is applied to the eye; on this account the one nearest to the eye is called the *eye-glass*, that towards the object-glass is called the *object-glass*. These glasses are situated upon the same axis *AB*, which passes through the center of the glasses, and to which they are perpendicular. The focal distance, or focus of the convex-glass, should be longer than that of the concave, and the lenses should be so disposed, that if *AF* be the focal distance of the convex lens *PAP*, the focal point of the concave glass should fall upon the same point *F*. Thus the interval *AB*, between the two glasses, is the difference between their foci, *AF* being the focal distance of the object-glass, and *BF* that of the eye-glass. When the glasses are so placed, a common eye will see distant objects distinctly, and will magnify in the same proportion that the line *AF* exceeds the line *BF*. Thus, supposing the focus of the object-glass to be six inches, and of the eye-glass to be one inch, the interval between them will be five inches; the length of the telescope and the objects will be enlarged six times, that is, it will appear under an angle six times greater than what they do to the naked eye.

After having explained to you the manner in which the glasses are to be disposed, in order to produce the desired effect, it remains for me to shew you why they represent the objects distinctly, and why they are magnified as many times as the line *AF* exceeds that of *BF*. With respect to the first, I must just remind you of what has been be-

fore observed, that we see objects best when the rays that proceed from them and fall upon the eye are nearly *parallel* to each other.

This observation being attended to, you must now consider another diagram, *fig. 14, pl. 6*. Let *V* be a point in the object towards which the telescope is directed, and as it is supposed to be very distant, the rays proceeding therefrom may be considered as parallel to each other; those therefore that fall upon the object-glass *Q A Q*, will be united at it's focus *F*, and being convergent there, will not be adapted to produce distinct vision for a common eye. Now it being the property of a concave glass to render rays more diverging, or to diminish their convergence, it will refract the rays *Q R*, *Q R*, so as to render them parallel to each other; so that instead of uniting at *E*, they will proceed in the direction *R S*, *R S*, parallel to the axis *A R F*, and thus the telescope will be fitted for distinct vision.

I have now to explain the principal effect of telescopes, that is, their magnifying power; a subject which I hope to render so clear, that no doubts shall remain on your mind.

1. Let *E e*, *fig. 3, pl. 7*, be the object placed on the axis of the telescope, which passes through the center of the two lenses. *E e* is to be considered as at an infinite distance.

2. If the eye placed at *A* look at this object, it will see it under the angle *E e*, called the visual angle. What we have therefore to prove is, that in looking through the telescope it will appear under an angle as much larger than this, as the focal distance of the object-glass exceeds that of the eye-glass.

3. As the effect of all the glasses consists in representing the object in another place, and of a certain size, all we have to do is to examine the different

different images, the last of which forms the object immediately viewed by means of the telescope.

4. Now the object Ee being at an infinite distance from the convex lens PAP , its image will be represented behind the glass at Ff , and AF will be the focal distance of this glass; the size of this image Ff , is determined by a strait line from the extremity e of the object through A the center of the lens; consequently this image is inverted, and as much smaller than the object, as the distance AF is smaller than the distance AE .

5. Now this image fF is to be considered as the object with respect to the eye-glass QBQ , since the rays that fall upon this glass are those which would form the image Ff , but that they are intercepted in their passage by the concave glass QBQ ; so that though the image is only imaginary, the effect is the same as if it were real.

6. The image Ff , that we may now consider as an object, being at the focal distance of the lens QBQ , will be transported to an infinite distance by the refraction of the glass. This new image is marked in the figure by Gg , of which the distance AG should be considered as infinite; and the rays being a second time refracted by the glass QBQ , will continue the same direction as if they came from the image Gg .

7. This second image Gg , being the object that is seen by him who looks through the telescope, we must consider its size. Now as it arises from the first image Ff , and the refraction of the glass QBQ , draw according to the general rule from B the middle of the concave glass a line passing through f the extremity of the first image, and it will mark at g the extremity of the second image.

8. Now as the spectator applies his eye at B, and as the rays that fall upon his eye are received as if they came from the image Gg, it will appear under the angle G B g evidently larger than the angle E A e, under which the object E e appears.

9. To compare these angles, I must inform you that the angle E A e is equal to the angle F A f, and the angle G B g is equal to the angle F B f. I have now therefore only to prove that the angle F B f exceeds the angle F A f, as much as the line A F exceeds the line B f.

10. To prove this, we must have recourse to certain propositions deduced from geometry, concerning the nature of sectors. You probably remember that a sector is an arch of a circle included between two radii; thus C M N, *fig. 4, pl. 6*, is a sector of a circle; C M, C N, the two radii; M N the arch or portion of the circumference. There are therefore three things to be considered in a sector: 1. The radius of the circle, as C M, C N. 2. The quantity of the arch M N. 3. The angle M C N.

11. Let us now consider the two sectors M C N, and m c n, *fig. 4, pl. 6*, of which the radii C M and c m are respectively equal. Geometry proves, that in this case the angles C and c are in the same ratio as the arcs M N and m n; or in other words, that the angle C is so many times larger than the angle c, as the arc M N is larger than the arc m n; or in more general terms, when the radii are equal, the angles are proportional to their respective arches.

12. In the two sectors M C N and m c n, *fig. 5, pl. 6*, the angles are equal, but the radii are unequal. The elements of geometry prove, in this case, that the arc M N is so many times greater than the arc m n, as the radius C M is greater than c m; or that the arcs are proportional to the respective radii when

when the angles are equal. The reason is evident, for each arc contains the same number of degrees; but the degrees of a large circle are as much larger than those of a small one, as the longer radius exceeds the smaller one.

13. In the two sectors $M C N$ and $m c n$, *fig. 6, pl. 6*, the arcs are equal, but the radii are unequal. Here the angle C , which answers to the longest radius, is the smallest, and that in the same ratio as the radii; or the angle c is so many times larger than the angle C , as the radius CM is larger than the radius cm ; or in more general terms, the angles are reciprocally proportional to the radii when the arcs are equal.

14. The last article comes more immediately to our purpose, with the addition of this observation, that when the angles are very small (as is the case in small Galilean telescopes), the arcs MN and mn do not differ sensibly from their cords, or the straight lines MN and mn .

15. We may now return to the former diagram. The triangles $F A f$, $F B f$, may be considered as sectors, and the arc $F f$ as common to both; consequently the angle $F B f$ exceeds the angle $F A f$, as much as the distance $A F$ exceeds that of $B F$; or the object $E e$ will appear in the telescope under an angle as much larger than that under which it appears to the naked eye, as the focal distance of the object-glass exceeds that of the eye, which was what I had to prove to you.

You will easily comprehend from what has been said, that very great advantages are not to be expected from a telescope constructed on this plan; for in order to obtain any considerable magnifying power, it must be made very long, a circumstance that renders it inconvenient in use. Besides this there are other disadvantages, among which the smallness of the apparent field is the principal.

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This naturally leads me to consider the nature of the *apparent field*, which is an article of great importance in all telescopes. When you direct a telescope towards the heavens or any other distant object, the space discovered appears of a circular form, and no objects are seen but what are contained within this circle; so that if you are desirous of viewing other objects, you must change the position of the telescope; this circular space is called the *apparent field*, or simply the *field of view*. Hence you will readily conceive, that it must be a great advantage to have a telescope with a large field, and that a small field must be considered as a defect.

As a large field is a great perfection in a telescope, it is often necessary to measure the field; this is generally attained by measuring the number of degrees contained in the space taken in by the telescope, when directed to the heavens, or to some very distant object. Thus as the apparent diameter of the full moon is about half a degree, if a telescope only takes in the moon, we say it's field is half a degree; but if you only see one half of the moon, the field would only be a quarter of a degree.

But in order to judge rightly of the field of a telescope, you must take in the magnifying power; for it is an universal maxim, that the more a telescope magnifies, the smaller is the field: nature here prescribes the boundaries. Let PAP , *fig. 3, pl. 7*, be the object-glass, QBQ the eye-glass of a telescope, EF the axis thereof, Ee an object at a great distance, seen under the angle $E Ae$, which represents half the diameter of the apparent field; which extend as much on one side the axis as on the other. The point E is the center of the field; the ray EA is not refracted as it passes through the middle of the glasses, perpendicular to their axis:
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in order therefore that this ray should enter the eye, the eye must be placed somewhere on the axis BF , behind the eye-glass, and so that the pupil may be on the line BF ; this is a general rule with respect to all telescopes. Let us now consider the visible extremity e of the object; and of this it is plain that the extremity e of the object cannot be seen unless the ray eA proceeding therefrom enters the eye.

Let us then consider the direction of the ray eA ; now, according to the laws of refraction, this ray is not refracted, because it passes through the middle of the object-glass A . This ray will therefore continue in the same direction to unite with other rays proceeding from the same point e , to form at f an image of the object represented by fF , the point f being the image of the point e of the object eE : but this ray meeting at m the concave glass, and not falling on the middle thereof, will be refracted; and instead of proceeding to f , will proceed in the direction mn , more diverging from the axis BF . You remember that the object-glass forms an inverted image of the object at Ff , and that Ff becomes the object with respect to the eye-glass, by which it is transported to Gg . The distance BG is as great as that of the object, because Ff is in the focus of the eye-glass.

With respect to the size of the images, the first Ff is determined by the strait line eAf , drawn from e through the middle of the glass PAP ; and that of the other Gg , by a strait line fBg , drawn from f through B the middle of the eye-glass. The ray Am directed towards the point f is refracted and proceeds towards mn , and this line continues backwards, passes by g , for the ray mn produces the same effect upon the eye as if it proceeded really from g . Now as mn diverges from BF , where the pupil of the eye is placed, it cannot enter

ter the eye if it diverges further than the limits of the pupil of the eye; so that in this species of telescope the field depends on the size of the pupil of the eye, and the larger this is the larger is the field; so that if the distance Bm does not exceed the same diameter of the pupil of the eye, and that this field may not be diminished, the eye should always be placed as near as possible to the eye-glass.

To determine then the size of the field in these telescopes, you have only to take the interval Bm equal to the semidiameter of the pupil, and then draw a line mAc from m , and the middle of the object glass, and this line will mark upon the object that extremity c which will be visible by the telescope, and the angle eAE will give the semidiameter of the field. From this it is very evident, that if the distance between the two glasses exceeds a few inches, the angle BAm will become very small, because the distance Bm is only about the $\frac{1}{16}$ of an inch. Now, in order to magnify much with these telescopes, the distance between the glasses must be considerably increased, in which case the field would be infinitely small; so that the extent of these telescopes is limited by the nature of their construction, and the optician, in order to produce great effects conveniently, is obliged to have recourse to other kinds.

A SUMMARY VIEW OF THE PROPERTIES OF THE GALILEAN TELESCOPE.

1. The focal distance of the object-glass must be greater than that of the eye-glass, or it will not magnify an object.

2. The magnifying power is equal to the quotient, arising by dividing the focal distance of the object-glass by that of the eye-glass.

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3. The rays proceeding from the eye-glass to the eye, are nearly parallel; if this does not suit the eye, the tube containing the eye-glass must be put in, or drawn out a little, till the object appears distinct.

4. The visible area of the object is greater, the nearer the eye is to the glass, and depends on the diameter of the eye's pupil, and of the object-glass; the field of view is therefore very small.

5. If this telescope be long, the visible area is so small as to render it useless; this arises from the smallness of the object-glass; but if this be broader, the object will be coloured and confused.

OF THE ASTRONOMICAL TELESCOPE.

The next kind, which is denominated the *astronomical telescope*, consists also only of two lenses, and both of them are convex. Let P A P, fig. 15, pl. 6, represent the object-glass which is convex, and whose focus is at F; Q Q a deeper and smaller convex lens for the eye-glass, which is to be fixed upon the same axis, so that its focus may coincide with the point F; holding the eye at o, so that the distance B O be nearly equal to the focal distance of the eye-glass. With a telescope constructed in this manner objects will be seen distinctly, and magnified in the same proportion as the focus of the object-glass exceeds that of the eye-glasses; but it represents all objects inverted, which does not lessen its value for astronomical purposes, but renders it inconvenient and improper for viewing terrestrial objects.

I have to explain to you, 1st, How this arrangement of glasses shews distant objects distinctly. 2d, Why it magnifies in the same proportion as the focus of the object-glass exceeds that of the eye-glass, and exhibits the objects in an inverted position.

position. And, 3d, Why the eye is not to be placed close to the eye-glass, as in the former construction.

1. The first article is proved in a similar manner to the same article in the preceding construction; the rays eP , eP , which are parallel to each other, before they fall upon the object-glass, are thereby refracted and united at it's focus; in order therefore for distinct vision, the eye-glass must re-establish the parallelism of the rays, which is effected by placing the eye-glass so that it's focus may be at F , and consequently the rays will proceed from it's parallel to each other, and fall upon the eye in that direction.

2. For the explanation of the second article, let us consider the object eE , *fig. 16, pl. 6*, supposed to be placed at an infinite distance. The image of this object formed by the object-glass, at it's focus, will be Ff ; this image will be inverted, and become an object for the eye-glass, and being situated at it's focus the image will be at an infinite distance, suppose at Gg , AG being considered an infinite distance as well as AE . Now to determine the size of this image, draw a strait line Bfg through B the middle of the lens, and the extremity f of the image. This second image is the immediate object of vision, and being at an infinite distance will be seen under the angle GBg ; but the object itself is seen under the angle $E Ae$. I scarcely need observe to you, that it is indifferent where the points A and B are taken, as the distance is considered as infinite. The triangles FAf , FBf , may, as in the preceding construction, be considered as sectors of a circle, the line Ff being an arch common to both, for the angles are so small that the chord may be taken for the arch; AE and BF are the respective radii, and the arches are equal; and of course, as I have proved before,

before, the angles Faf (or $E Ae$) and FBf (or GBg) are in the same ratio as the radii BF and AF . Therefore the angle GBg , under which the object is seen by the telescope, is so much larger than the angle $E Ae$, under which the object is seen by the naked eye, as AF is larger than BF .

3. With respect to the place of the eye, the proper situation thereof is determined by the field; for if you remove it either way from the focus of the eye-glass, the field is diminished. It is a great advantage in telescopes of this construction, that by removing the eye from the eye-glass, the field may be to a certain degree increased; and it is owing to this that the magnifying power of these may be so much increased, which will be evident by the following considerations:

1. Let Ee , *fig. 17, pl. 6*, be the object at an infinite distance, e the extremity visible by the telescope, whose glasses PAP , QBQ , are situated on the axis $EABO$; we have now to consider the direction of the ray e , which proceeds from the extremity of the object through the middle of the object-glass; for the other rays proceeding from the same point e , only contribute to strengthen the effect produced by this ray.

2. The ray eA passing through the middle of the glass PP is not bent, but passing on in the direction AfM , passing by the extremity f of the image, and falling upon the eye-glass at M . Here it is necessary to observe, that if the eye-glass is not large enough to reach M , this ray would not enter the eye, and the point e would be invisible; that is, in other words, the extremity e must be placed nearer the axis, to make the ray AfM fall upon the eye-glass.

3. This ray AM will be refracted by the eye-glass; the mode of it's refraction will be easily investigated: to this end let us consider the second
image

image Gg. Now the line B prolonged, falls upon g, the extremity of the second image, and the refracted ray takes the direction NO, which being prolonged falls upon g.

4. Since then the two lines ON and Bf meet at g at an infinite distance, they may be considered as parallel to each other; therefore, to determine the position of the refracted ray NO, we have only to draw a line parallel to the line Bf.

5. From hence it is evident, that the ray NO must meet with the axis of the telescope as at O; and since generally when the magnifying power is great, the point F is much nearer the glass QQ than the glass PP, the interval BM will be a little larger than the image Ff; and as the line NO is parallel to fB, the line BO will be almost equal to BF, the focal distance of the eye-glass.

6. The eye being placed at O will receive not only the rays which come from the middle of the object E, but also those which proceed from the extremity e, and consequently those which come from all other parts of the object; the rays from BO and NO will fall at the same time on the eye, however small the pupil may be; the field therefore in this construction does not depend upon the size of the pupil, provided the eye be placed at O, but the moment the eye is removed from O, the apparent field is diminished.

7. If the point M was not at the extremity of the eye-glass, it would transmit rays that were further removed from the axis, and the field would be larger. Therefore to determine the field of which the telescope is capable, draw from A the middle of the object-glass, to M the edge of the eye glass, the line AM; this continued to e, the object will mark the visible extremity thereof, consequently the angle EAe or BAM gives the semidiameter of the apparent field, which is consequently

requently augmented in proportion as the eye-glass is larger. In the first kind the field depended on the aperture of the pupil of the eye, in this it depends on the aperture of the eye-glass.

By the object-glass the object is carried from Ee to Ff ; by the eye-glass it is as it were removed from Ff to Gg ; the image Gg , from being at such a distance, is seen distinctly. This image is seen by the eye at O under the angle GOg or BON , while the object is seen by the naked eye under the angle $E Ae$; the telescope therefore magnifies in the same proportion as the angle BON is greater than the angle $E Ae$. Now as NO is parallel to Bf , the angle BON is equal to the angle Fbf , and the angle $E Ae$ is equal to FAf ; therefore the magnifying power may be determined by the proportion between the angles Fbf and FAf . Now Fbf is as much larger than FAf , as the line AF , is larger than the line Bf , or as much as the focus of the object-glass exceeds that of the eye-glass.

SUMMARY OF THE PROPERTIES OF THE ASTRONOMICAL TELESCOPE.

1. The magnifying power is in the proportion of the focal distance of the object to the eye-glass.

2. The rays emerging from the eye-glass to the eye should be parallel for a good eye; if this does not suit another eye, then the tube must be pushed in or pulled out till the object appears distinct.

3. The apparent magnitude of an object is the same wherever the eye be placed, but the visible area is the greatest when the eye is nearly at the focal distance of the eye-glass.

4. The object is always inverted.

5. The visual angle depends on the breadth

of the eye-glass; for it is equal to the angle which the eye-glass subtends at the object-glass from Ee.

There are two other circumstances relative to the perfection of telescopes, which we have now to consider; the *brightness* or *quantity of light*, and the *distinctness* with which objects are seen.

With respect to brightness, the telescope may be considered as perfect when it represents them as bright as they are seen by the naked eye, which is the case when the aperture of the pupil is filled by the rays which come from each part of the object after being transmitted through the telescope; so long as a telescope furnishes a sufficient quantity of rays to fill the aperture of the pupil, no greater brightness can be desired, for a greater quantity would be useless. But as the size of the pupil varies, it has been usual, in considering this subject, to consider it of about $\frac{1}{16}$ of an inch diameter: when you consider that the light of the sun is reckoned to exceed that of the moon 300,000 times, you will easily perceive that a small diminution of light is not of any great consequence. Let us, however, examine the rays transmitted by the telescope, and compare them with the assigned diameter of the pupil; this will be clearer by attending only to one point of the object, that, for instance, which coincides with the axis of the telescope.

1. The object being at an infinite distance, the rays which fall upon the surface of the object may be considered as parallel to each other; therefore all the rays which come from the center of the object will be contained between the lines eP , eP , parallel to the axis EA , *fig. 15, pl. 6*. All these rays taken together are named the pencil of rays, which fall upon the object-glass, and the thickness of this pencil is equal to the aperture of the object-glass, whose diameter is PAP .

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2. This cylindrical pencil of rays is changed into a conical one PFP by the object-glass; after having crossed at the focus F , the rays proceed and form another cone, the apex of which is at the focus, and the base is the eye-glass. Now it is evident, that the base of the cone mm is as much smaller than the pencil PP , as the distance FB is shorter than the distance AF .

3. Now the rays Fm , Fm , after passing through the eye-glass, again become parallel to each other, and form the pencil no , no , which enter the eye, and paint thereon the image of that point from which they originally proceeded.

4. Every thing turns now upon the size of the pencil of rays no , no , which enters the eye; if the diameter thereof is equal or greater than the aperture of the pupil, it will be filled, and the object will be seen with all possible brightness.

5. But if the size of this pencil be much smaller than that of the pupil, it is clear that the representation would be obscure, which is a great defect in any telescope; to prevent which, the last pencil of rays should be rather more than $\frac{1}{10}$ of an inch in diameter, though it would be better if it was nearly $\frac{1}{8}$ of an inch.

6. Now it is evident, that the size of the last pencil of rays depends on the size of the first by which it is formed, which is easily determined; for we have only to see how much smaller nn is than PP , the aperture of the object-glass. Now PP is to nn as AF to BF , on which the magnifying power depends; therefore the magnifying power shews how much larger the pencil EP , EP , is than the pencil no , no .

7. From hence it is evident, that the aperture of the object-glass should be increased in proportion as the magnifying power is augmented; con-

frequently if this proportional diameter cannot be given to the object-glass, the telescope will be defective.

Opticians have established, as a general rule, that the aperture of a lens should always be smaller than half its focal distance.

Distinctness of expression is confessedly the most important article in the nature of telescopes, and to attain it, has exercised the genius, and called forth the abilities of a Newton, Dollond, Euler, D'Alembert, &c.

You may remember that I assumed as a principle, that a convex lens united in one point the image of all the rays proceeding from any given point of an object. If this was rigorously true, the images formed by lenses would be as well terminated, and as perfectly defined, as the object itself.

But this principle is only true to a certain degree, and with respect to those rays that are near the center of the lens; for the rays which pass through the glass at a distance from this center are not collected in the same point with those which pass through the middle, and from this double image great indistinctness arises.

To render this more clear, we must again have reference to a diagram. Let *PP*, *fig. 7, pl. 7*, be a convex-glass; *E* an object situated on the axis thereof; *E* the point coinciding with the axis, and sending out rays *EM*, *EN*, *EA*, *EM*, *EN*, on the surface of the glass. We have to consider how the direction of these rays is changed by the lens.

1. The ray *EA* passing through the middle of the glass is not refracted, but proceeds in the same rectilinear direction *ABE*.

2. The rays *EM*, *EM*, which are very near to *EA*, are only refracted in a small degree, but so as to unite somewhere; as at *F*, which point of union

union we have considered as the focus of the lens.

3. The rays EN , EN , which are further from the axis, or nearer the edge of the glass, are refracted somewhat differently, so as to meet at G nearer the lens than the point F , forming a separate image Gg .

4. This circumstance concerning the rays which fall upon the lens at a distance from the center, and there forming another image of the same point, separate from that which is formed by the rays that pass near the center of the lens, though I have not noticed it to you before, merits considerable attention.

5. From hence you will perceive, that the first image Ff is formed only by the union of those rays which are very near the middle of the glass, and that a succession of images is formed by the rays that are more and more removed from the axis, till at last you come to those which fall near the edge of the lens, which form the image Gg .

6. An indefinite number of images are therefore formed between Ff and Gg , by the rays that fall upon the surface of the lens between the axis and the edge thereof.

7. This succession of images is termed the *aberration arising from the sphericity* of the glass, or the diffusion of the image; and it must be evident to you, that when these rays enter the eye, the vision obtained thereby of the original point must be confused and indistinct; but if the space FG could be reduced to the point F , there would be no confusion or want of distinctness.

8. This diffusion or dispersion of the rays is greater in proportion as the arcs PAB , PBP , are larger segments of their respective circles; and you will perceive from thence, that very thick and convex lenses are to be rejected; thus, in this figure,

Kk 3

where

where the arcs P A P and P B P are the fourth part of the whole circumference, the confusion would be insupportable.

9. Some authors who have written upon this subject, say, that the arch forming the lens should not contain more than 20 degrees of it's respective circumference.

10. But if the lens be designed for the object-glass of a telescope, it must be formed of an arc containing fewer degrees; for though the dispersion of the rays may be insensible in itself, the magnifying power multiplies it as often as the object itself: hence the greater the magnifying power, the smaller the number of degrees that should be embraced by the object-glass.

When the dispersion of the rays is very great, it may be lessened by covering the edge of the lens with an opaque ring, leaving only a small aperture round the center of the lens; by this means *distinctness* is restored, but *brightness* is diminished, and as much is lost on one hand as is gained on the other; the more so as every increase in magnifying power requires a proportional increase of aperture. Opticians have therefore with much pains and assiduity endeavoured to discover some means of correcting this dispersion, without lessening the aperture of the object-glass.

The focus of the rays which pass through the middle of a convex lens, is, as you have seen, further from the lens than the focus of the rays which pass near the edge of the glass. Now it has been observed by opticians, that a concave lens produces a contrary effect; they have consequently investigated this subject, in order to see whether they could not combine a concave with a convex lens, so as to correct or destroy this aberration, while the compound lens produced the ordinary effect of a simple object-glass. We have already shewn
you,

you, that concave lenses are considered according to their focus as well as convex lenses, but with this difference, that the focus of a concave lens is *virtual* or *imaginary*, and falls before the lens, while that of the convex is *real*, and falls behind the lens. These circumstances being considered, opticians reasoned in the following manner.

1. If you place a concave lens behind a convex one of the same focal distance, the rays that would have been united in it's focus are so refracted as to be rendered parallel to each other, as they were before they entered the glass.

2. In this case the concave lens destroys the effect of the convex, and the rays go on in their original and natural order.

3. If the focal distance of the concave lens is smaller than that of the convex, the effect would be greater, and the rays rendered diverging. Thus the incident parallel rays, LM, LA, LM, *fig. 8, pl. 7*, passing through the glasses MP, QQ, will go on diverging in the direction NO, BF, NO. These two glasses therefore, when combined, produce the same effect as a single concave, that would give to parallel rays the same degree of divergence. Two glasses combined together, of which the concave has a smaller focal distance than the convex, are equivalent to a single concave glass.

4. But if the concave lens QQ, *fig. 9, pl. 7*, has a longer focal distance than the convex lens PP, it will not even render the rays parallel that the convex lens would unite at it's focus F, but it will however so far lessen their convergence, that instead of meeting at E they will unite at O, a point further from the lens.

5. The combined lenses in this instance produce the same effect as a single convex lens, whose focus would be at O. It is evident then, that it is possible to vary infinitely the combination of two

lenses, the one convex and the other concave, so that the combined lenses may be equivalent to any given convex lens.

6. Such a combined lens may be applied to a telescope instead of a single lens, and the effect with respect to magnifying power will be still the same; but the degree of diffusion or dispersion in the rays will be very different; it may be greater or much less than in a single lens: in the last case the double object-glass will be far preferable to a single one.

7. But what is still more advantageous, it is possible so to arrange them, that this dispersion may be destroyed. Calculation discovers these combinations, but the hand of the artist is not equal to the execution.

The combination of two lenses in the manner that I have here described, forms what is called a *compound object-glass*; the end to be attained is, that the rays which pass through the lens, as well those at the edge as those at the center, may be united in a single point, and form only one image, without such a dispersion of the rays as takes place in a single object-glass.

Many are the advantages that would be derived from such a combination; the object would appear more distinct and better terminated, because the vision would not be confused by that mixed succession of images produced by a single object-glass. This dispersion of the rays is one of the principal reasons which forces us to make use of very long telescopes, in order thereby to diminish the effect of the dispersion; but if this dispersion was entirely destroyed, much smaller ones might be used, that should be productive of the same effect.

It will be necessary to observe to you here, that the sides or faces of the lenses may be formed

in

in different ways, almost *ad infinitum*, and yet the focus remain the same; this is effected by forming the sides of equal or unequal radii, as will be evident by considering an example. Let us suppose then a convex lens, whose sides have been formed on a tool of 24 inches radius, consequently each face is the segment of a circle of 24 inches radius; it will be equally convex on both sides, and be of 24 inches focus, as commonly estimated; but as the focus depends on the refraction, it varies according to the density of the glass; generally the focal point is nearer the lens than the radii of the face, sometimes a tenth or twelfth part, so that the lens that we have supposed to be ground on a tool of 24 inches radius will have it's focus at 22 inches.

By making the surfaces unequal, an infinite variety of lenses may be formed, that shall all have the same focus; *ex. gr.* if one face be taken of a smaller radius than 24 inches, the other must be taken of a longer, the one thus compensating for the other. The following table exhibits a view of some of the varieties with which the two faces of a lens may be worked, and yet produce the same effect.

Glasses.	Radius of 1st face.	Radius of 2d face.
1	24	24
2	21	28
3	20	30
4	18	36
5	16	48
6	15	60
7	14	84
8	13	156
9	12	infinite.

In the last or ninth form the radius is only 12,
the

the half of 24 inches ; but the other face the segment of a circle, whose radius is infinite, and therefore may be considered as a strait line ; and therefore this lens would be a plano-convex.

If you are desirous that one of the faces be formed of a smaller radius than 12 inches, the other face must be concave, and the glass will be convexo-concave, or what is termed a *meniscus*. The following table is a specimen of figures for this form :

Meniscus.	Rad. of 1st face.	Rad. of concave.
10	11	132
11	10	60
12	9	36
13	8	24
14	6	12
15	4	6
16	3	4

You have here then sixteen different kinds of lenses, whose foci will all be at the same distance or point. If the focus only were considered, it would be indifferent which of these were employed ; yet it is not so with respect to the dispersion of the rays, for in this respect they differ considerably ; it is much more in some than in others. Amongst these, that of the seventh kind is one of those where the dispersion is least, being nearly one half less than it would be if the lens were equally convex on both sides ; and it is therefore of an advantageous figure for a single object-glass.

From what has been said, you perceive, that in order to correct the aberration that arises from the sphericity, it is necessary to resolve a problem which will discover what are the proper radii for the two surfaces of a lens, so that the dispersion of the rays may be annihilated ; the solution requires
a con-

a considerable knowledge of the more profound parts of geometry, and therefore does not come within the compass of these Lectures; enough, however, has I hope been said to render the subject clear to you, and to point out the necessity and nature of these investigations.

There is still another *aberration* to be corrected, another cause of *dispersion* in the rays to be counteracted or destroyed; this seems more important, and more difficult to be cured, as it does not depend on the *glass*, but on the nature and properties of the *rays of light*. You no doubt remember what I have already told you respecting the variety in the rays, according to the different colours they occasioned, that is, that they were of different degrees of refrangibility; thus, that the red-making rays were the least refracted, and the violet-making rays the most refracted, all the other rays falling within these two extremes.

Thus when a beam of light falls obliquely upon a piece of glass ABCD, *fig. 10, pl. 7*, instead of proceeding in the same direction PQ, it is not only refracted but separated into several rays Pt, PS, Pr, Pv, of which the first Pt, that is the least refracted, represents the red-making ray, and the last Pv, the violet-making ray. Their divergence is indeed much less than that which is represented in this diagram, but sufficient to become sensible.

From this difference in the refrangibility of the rays, arise various phenomena with respect to dioptric glasses, among which are the following:

1. Let PP, *fig. 11, pl. 7*, be a convex lens at a considerable distance AO, from the object Oo, to determine the image formed by the lens, without taking into consideration the aberration already discussed; or what comes to the same thing, only con-

considering the rays that pass through the middle of the lens.

2. Let us suppose that the object *Oo* be red, and the rays proceeding therefrom will be all red-making rays, and will form somewhere a red image *Rr* of the object, and *R* will be the focus of the red-making rays, or those which have the least refraction.

3. But if the object *Oo* be violet, the rays will be more refracted, and the image *Vv* will be nearer the lens, and the point *V* will be the focus of these rays.

4. If the object be of any of the intermediate colours between these two, the image will fall between *R* and *V*.

5. But if the object is not of an homogeneous colour, (or is white,) as is the case in most bodies, the different kinds of rays are separated by refraction, and each kind forms an image apart; that formed by the red-making rays will be found at *Rr*, and that by the violet at *Vv*, and the space *RV* will be filled by images of the intermediate colours.

6. The glass *PP* will represent an indefinite number of images of each object *Oo* formed in the space *RV*, and situated in the order of the prismatic colours.

7. Each of these images will be distinct in itself, but taken together productive of a very sensible confusion.

8. Here then is another species of dispersion totally independent of that which we have already treated of, and tinging each image with a particular colour.

9. This dispersion depends considerably on the focal distance of the lens, being about $\frac{1}{10}$ th part; when the focal distance is 28 feet, the space *RV*

is

is about 1 foot. If the lens was of 56 feet focus, RV would be about 2 feet.

I have now explained to you a second source or cause of indistinct or imperfect vision; namely, that which arises from the different refrangibility of the rays: which requires a different mode of correction from the former error, which I shall treat of when we come to speak of ACROMATIC TELESCOPES; and only shew here, how the error may be in a degree corrected, by the disposition of the eye-glasses.

1. It is certain, that the object-glass forms an infinity of images of each object, successively ranged in the space of diffusion, each of which tinged with it's proper colour.

2. Each of these images becomes an object, with respect to the eye-glass, with it's respective colours; and if, instead of one eye-glass, more are used, the same thing still takes place.

3. Let us therefore, in this diagram, consider the last images that the telescope forms for the eye at O , and let Rr be the red image, and Vv the violet; the other colours falling within this space, according to their different degrees of refrangibility. The lenses are not exhibited in the figure, because we are only to consider the manner in which the images are seen by the eye, supposing the distance from the eye to them to be very great.

4. All these images, together with the intermediate ones, are situated on the axis ORV of the telescope, and terminated by a strait line rv , that we may call the terminator of all the images.

5. According to the representation in the figure, the red image Rr is seen by the eye at O , under the angle ROr , which is larger than the angle VOv , under which the violet image Vv is viewed; the violet rays which enter the eye, are therefore mixed with the red rays which proceed from the part Rr of the image Rr ; and, conse-

quently

quently, there is a very great confusion of the images.

6. But the ray $O r$ not being mixed with the others, the extremity or edge of the image will be red; but will soon after be mixed with the other colours, forming the iris, which is so common in other telescopes. If the largest image was the violet, the confusion would be as great as before, with only this difference, that the extreme edge would be violet, not red.

7. Much of the confusion will depend, therefore, on the position of the terminator $r v$; and from the various situations that may be given to it, this confusion will be sometimes greater, and sometimes less.

8. Suppose that the images were so arranged, that the terminator $v r$ passed directly into the eye by a single ray $v r O$; then the extremities of the image, and all the points which answer to one point in the object, would form only one point in the eye, and the point of the object would be represented distinctly.

9. This advantage is to be obtained when the terminator, being prolonged, passes directly into the eye; and such a position is to be sought for in the arrangement of the eye-glasses.

Before we enter upon acromatic telescopes, I shall endeavour to explain the nature of telescopes with three eye-glasses, in which the image is seen erect.

1. Let the four glasses A, B, C, D , *fig. 7. pl. 8*; in the tube represent the telescope; the glass A , directed towards the object, is called, as we have before said, the object-glass, the three others the eye-glasses: the four glasses are convex.

2. Let us consider the effect produced by each eye-glass, the object $o O$ being supposed at a considerable distance. The object-glass will form an image of the object at $P p$, its focus; the size of this

this image may be found from o , through the middle of the glass A . I have not drawn this line, in order to avoid confusion from a multiplicity thereof.

3. The image Pp now becomes an object, with respect to the eye-glass B , which is so placed that the interval Bp is equal to the focus of B ; by this the second image is transported to Qq , and is inverted, as well as the first Pp ; it's size is determined by a line drawn from the middle of the glass B , through p .

4. The interval AB , between these two lenses, is equal to the sum of their foci, forming the astronomical telescope already explained; the image being inverted, and magnified as many times as AP exceeds BP ; but instead of the eye-glass, another lens C is placed behind B ; with respect to this lens, the image Qq becomes the object, which being at a considerable distance, the lens C forms an image thereof at it's focus r .

5. The image Qq being inverted, that of Rr will be inverted, and terminated by a right line drawn from q through the middle of the glass C , which will pass by r ; consequently, the three lenses A, B, C , give the image of the object Oo at r , and this image is upright.

6. You have now only to place the third lens so that the interval DR be equal to the focus. By this the image will be again, as it were, transferred to an infinite distance Ss , of which the size will be determined by a strait line drawn through the middle of the glass d , and passing by the extremity of the image r , and the image Ss will be seen by the eye, instead of the object Oo .

7. It is easy now to determine how many times a four-glassed telescope magnifies the object. For this purpose, you have only to consider the lenses in pairs, A, B , and C, D ; each of these, taken separately, being an astronomical telescope. The first

first pair of glasses, A and B, magnify the object as many times as the focal distance of A exceeds that of B, and just so many times the image Qq exceeds the object Oo.

8. Qq being now considered as the object, is magnified as many times as the focus of C exceeds that of D; these two powers added together, give the total magnifying power of the telescope.

Fig. 11, pl. 4, is a perspective view of a model designed to illustrate the nature of a four-glass telescope, which shews the objects in their true positions; the rays of light are represented by silk strings of different colours, so that their progress is easily traced; A B C the object, D E the object-glass, I K, M N, Q R, the eye-glasses, so placed that the foci of D E and I K meet in G. Those of I K and M N may meet at L, and those of M N, Q R, may meet in g. From the progress of the rays, you perceive that the image at H T is inverted, that the rays proceed from I K in a parallel direction, crossing at L, from whence they go on to M N, pass through it, and are thereby converged into a focus, and form a second image f g h erect, which image will be viewed by the eye in the focus of the eye-glass Q R.*

SUMMARY VIEW OF THE PROPERTIES OF THIS TELESCOPE.

The magnifying power is in proportion as the focal distance of the object-glass is to the focus of the eye-glass.

It shews the object erect, but not so bright as in the telescope with two lenses; because the other eye-glass reflects a considerable quantity of light which is lost.

The

* At *fig. 12, pl. 4,* another model is represented, formed with lenses, to try experimentally the places of the images.

The visible area depends on the breadth of the eye-glass.

The brightness of an object seen through a given telescope, is greater in proportion as the aperture of the object-glass is greater.

If the aperture and focus of the object-glass remain the same, an object appears brighter or fainter according to the greater or less focal distance of the eye-glass, that is, according to the magnifying power; for the same quantity of light being spread over a greater or smaller surface, renders the image obscure or brighter.

ON THE CONSTRUCTION AND MAGNIFYING POWER
OF TELESCOPES MADE WITH SEVERAL EYE-GLASSES.

In this diagram, *pl. 8, fig. 1*, A is the first, B the second, C the third, D the fourth, E the fifth eye-glass, and O the object-glass. DA the axis of the telescope is also the common axis of all the lenses; I m w an oblique pencil passing through the object-glass, and falling on the extreme edge of the lens, which is next the object-glass. O w is the axis of the pencil (represented by a black line), shewn as refracted successively into the lines w v, v t, t s, s r, r a, cutting the axis of the telescope (when produced) in the points ϵ , δ , γ , β , α , respectively. O is the focus of this oblique pencil after refraction at the object-glass; e, d, c, b, the successive foci of this pencil after refraction at each of the eye-glasses. From each of these foci draw perpendiculars to the axis of the telescope, and these perpendiculars, o x, e g, d h, c z, b y, will be places and magnitudes of successive images either *real* or *imaginary*; *real* when the image is actually formed, so that it would be visible if the rays were received upon a white paper; *imaginary* when the rays after refraction proceed as if they came

from or tended to such an image, although this image is not actually formed. *When the image is real, the rays of each pencil actually come to a focus.* When it is imaginary, these rays after refraction diverge from or converge towards such a focus, but are never actually united.

Although each lens has it's image either real or imaginary, yet there are only two real ones in the construction here delineated, the first e.g. inverted, the second by upright.

When the number of real images is even, the object will be seen upright; when that number is odd, the object is inverted. Galileo's telescope, in which there is no real image, shews the object upright; it cannot therefore be applied to instruments in which cross wires are necessary, because the wires cannot be so placed as to be seen distinctly together with the object.

All that is essential to the construction of telescopes is, only that the rays of the same pencil, which enter parallel, should likewise emerge parallel, for the object will in that case be seen distinctly; the intervals and focal lengths therefore of all the lenses, except one, may be assumed at pleasure, from whence that one must be determined. This assertion of most writers on optics is true, if nothing else be attended to but the course of a few rays coming from a single point in the axis of the telescope, and it be only required that the middle of the object be seen distinctly; but the case is very different, if it be required that all parts of the object should be seen as far as may be equally distinct, for then the aberration of the extreme pencil in passing through the eye-glasses must be taken into consideration; and the number, place, and focal lengths of the eye-glasses, must be such as may lessen at least, if not remove these aberrations.

It may be observed, that generally in any single lens, the greater the focal length, and the less the aperture, the less will be the aberration of the refracted rays. That construction is therefore (*cæteris paribus*) the best, in which the eye-glasses have large focal distances and small apertures; those especially that are concerned in forming the last image. As to the single lens by which the last image is viewed, it may be allowed to have a short focal length, particularly if its aperture may be contracted; for though this lens magnifies the faults already made in the last image by the other glass, it does not create new faults.

Among the various sorts of telescopes made with convex lenses, and designed to shew the object upright, those with four or five glasses are preferable to those with fewer. The fewer lenses there are in the eye-tube, the greater must be the refraction of the extreme pencils at each lens, supposing the sum of all the refractions, or the whole change in the direction of the pencils, to be the same. Now though the number of refractions is increased, yet if the quantity of each refraction be proportionably diminished, the sum of all the aberrations in these pencils will be greatly lessened; and the loss of light, by passing through more glasses, will be very inconsiderable.

Agreeable to this principle, it is found, that an object seen through two double convex lenses, both of a size, and put close together, appears distincter near the edges of those lenses, than if seen through one lens whose focal length is equal to that of the other two so combined together: likewise two equal plano-convex lenses shew an object distincter at their edges when combined with their convex sides touching each other, than contrariwise. Thus then the aberrations from the figure of the eye-glasses may be lessened, by in-

creasing the number and diminishing the quantity of the several refractions.

The lens E, which intercepts the rays before the first image is formed, diminishes the magnifying power, but improves the distinctness of the telescope, by lessening the diameter of the apertures of the deep lenses D and C. The extreme pencil OW, which diverges from O, being refracted by this lens into WV, is made to converge towards the axis of the telescope, so that if produced it would meet at ϵ . By this means the semi-diameter of the lens D is reduced to DV, whereas if the first real image had been formed at Ox by the object-glass only (the extreme pencil Oo in that case continuing to diverge), the semi-diameter DV must have been greater than the image Ox, to take in the same field.

The rays belonging to this and every other pencil which diverge from e g, the first real image must be made to converge again by the two lenses D and C, that a second real image may be formed upright. Two lenses are employed for this purpose, because the errors in the second image will be lessened by their contrary refractions; supposing therefore their convexities equal, and that the rays of this pencil (refracted into vt) go parallel or nearly so between the lenses D and C, then it is evident, that the focal length of D must be equal to the distance ev ($=gD$), or nearly so; therefore the lenses D and C, having a shorter focal length, will by no means admit of an aperture, whose semi-diameter is greater than ox. It may be further observed, that this pencil, which at first diverged from the axis of the telescope, in the angle wOE and v δ D, by the interposition of the lens E, this change is made at two refractions (at w and v), which must otherwise have been made by the refraction of the lens D only.

In like manner, the other lens B, which intercepts the rays just before the second real image is formed, diminishes indeed the magnifying power, but makes the telescope more distinct. The extreme pencil we have been considering, after refraction at t by the lens c, diverges from the axis of the telescope, proceeding as if it came from the point γ ; but being refracted by the lens B into sr, is made to converge, so that if produced it would meet the axis of the telescope in β . This lessens the last image, reducing it from cz to by; and as it is this image which is viewed by the eye through the eye-glass A, the interposition of the lens B lessens the magnifying power, the eye-glass A remaining the same. The extreme pencil Sv thus converging upon the eye-glass A, the semidiameter of this glass will be reduced to Ar; whereas, had the lens B not been interposed, (the extreme pencil tsc continuing to diverge from γ) the semidiameter of this eye-glass must have been greater than the image cz, to take in the whole field. As a small aperture of the eye-glass A is sufficient to take in the whole field when the pencils thus fall upon it converging, this lens may be allowed to have a shorter focal length, and thus compensate for the loss of magnifying power by the interposition of the lens B, without increasing the aberration of the extreme pencils.

You may prove this experimentally by taking out the second eye-glass, then drawing out the tube to make the telescope distinct again, and you will find the magnifying power increased, the field diminished, and perhaps indistinct near the edges.

OF ACHROMATIC TELESCOPES.

To render this subject plain and clear, I shall recal to your mind a few of those principles which

we have already explained. Thus you know that a ray of light, refracted by passing through mediums of different densities, is at the same time proportionally divided or spread into a number of parts, called homogeneal rays, each being the exciting cause of a different colour; and that these rays after refraction proceed diverging.

That a ray of light passing obliquely from a rarer into a denser medium, is refracted towards the perpendicular; but when it passes from a denser into a rarer medium, it is refracted from the perpendicular.

That when a ray of light is refracted out of air into a given medium, or out of a given medium into the air, the sines of the angles of incidence and refraction are in a constant ratio.

But light consisting of parts which are differently refrangible, each part of an original or compound ray has a ratio peculiar to itself; and that the more the heterogeneous ray is refracted, the more will the colour-making rays diverge, as the sines of the homogene rays are constant, and equal refraction produces equal divergencies.

From hence you have also been shewn, that the rays when passing through a convex lens, instead of uniting in one focus, form as many foci of different distances, as there are coloured rays; and that the prismatic colours or irises, which appear towards the borders of convex lenses, render the images confused.

The indistinctness of vision produced by this cause, which is sensible in telescopes of a small aperture, increases into so high a ratio upon enlarging the aperture, namely, as the cubes of the diameters, that unless this confusion of colours was corrected, it would be impossible to increase greatly the power of refracting telescopes, without extending their length to a very inconvenient size.

It

It was known before Mr. Dollond's, that different transparent bodies possessed some a greater and some a less refractive power; and it was taken for granted, until he evinced to the contrary, that the dispersive power of the coloured ray was in every transparent body proportional to it's mean refractive power; or in other words, that the refraction of the coloured rays, whatever body they passed through, were always in a constant determinate ratio to each other. Consequently, if the dispersion produced by a convex lens, were counteracted by another lens or medium of a concave form, that the refraction would also be totally destroyed; and that this would be the event, if the two lenses were even made of the same matter. Upon this supposition, it was impossible ever to correct this fault in dioptric telescopes.

While opticians continued to think, that equal refractions would, in every sort of medium, necessarily produce equal divergencies, and that consequently equal and contrary refractions would destroy each other, and that the divergency of colour from one refraction would be corrected by the other, there could be no possibility of producing any refraction that would not be affected by the different refrangibility of light. For, however a ray of light might be refracted backwards and forwards by different media, provided it was so done that the emerging ray was parallel to the incident one, it would always be white or colourless; but if it came out inclined to the incident ray, it would diverge and be ever after coloured.

This erroneous supposition was countenanced by an experiment of Sir I. Newton, of placing two prisms, one made of glass contained within a prismatic vessel, filled with water, in such manner that the rays of light which were refracted by the

prism of glass should pass through and be refracted in a contrary direction, and in as great a degree by the water prism; by which means he relates, that light thus restored to it's original direction was white and free from colours.

"In the year 1757, Mr. John Dollond repeated this famous experiment of *Newton*, of refracting a ray of light through prisms of glass and water, placed with their refracting angles in opposite directions, and so proportioned to each other that the ray after these opposite refractions emerged parallel to the incident ray. According to the Newtonian doctrine, there ought here to have been no divergency of the heterogeneous rays, and no colour produced by these equal and opposite refractions.

But this was *not* the result of the experiments; the ray was very sensibly coloured. Mr. Dollond, finding that opposite refractions produce colour notwithstanding the parallelism of the incident and emergent ray, concludes, that by properly adjusting the angles, he might effect an inclination of the refracted to the incident light, without any colour or divergency. Experiment proved his reasoning to be just.

It may be proper to observe here, that those media are said to have the same *mean refractive density*, which, under equal obliquities of incidence, equally refract the mean refrangible ray; and two media are said to have the same *dispersive power*, which produce an equal inclination of rays of the same colour to the mean refrangible ray, when the whole refraction of the mean refrangible ray is equal in both.

Let the vertex of a flint glass prism, the refracting angle of which is equal to $23^{\circ} 40'$, be applied to the base of a crown glass prism, the refracting angle

*angle of which is equal to 25° ; a ray of solar light will pass through the prisms when their surfaces are contiguous, but the emergent ray will be coloured.**

The ray is supposed to fall perpendicularly upon the surface of the prism, whose refracting angle is the greatest.

The position of the prisms in this experiment is such, that the effects of refraction upon the parallelism of the homogeneous rays passing through them are contrary to each other, and consequently if they were equal the rays would emerge parallel. But the flint prism, by its greater dissipating power, more than counteracts the separation of the rays caused by their passage through the first prism, which was equal $38\frac{1}{2}$ minutes; and inverting the order of the colours, causes the red and violet rays to emerge, inclined to each other at an angle of $12\frac{1}{2}$ minutes, sufficiently great to produce a sensible tinge of the prismatic colours in the emergent rays.

Every thing remaining as in the last experiment, let the vertex of a crown glass prism, the refracting angle of which is 10° , be applied to the base of the flint prism. If a ray of solar light passes through the three prisms, when their surfaces are contiguous, the emergent ray will deviate about $5^{\circ} 37'$ from the course of the incident ray, but will be colourless.

In this case the two crown glass prisms refracting the ray in the same direction, cause it to deviate from the course of the incident ray about $5^{\circ} 37'$ more than the deviation in the contrary direction arising from refraction through a flint prism.

But the flint prism, by its greater *dissipating* power, exactly counteracts the separation of the rays caused by refraction through the other two prisms,

* Atwood's Analysis of a Course of Lectures, p. 164, 165.

prisms, so that the homogeneal rays emerge at length parallel, and of course colourless.

Now this was what was wanted; for you have seen, that the difficulty which chiefly impeded the improvement of telescopes was, so to refract a ray while it deviated considerably from its original course, that the dispersion of the homogeneal rays might be counteracted, and that by this means they might all emerge parallel, and of course free from colour; and this is, you perceive, effected by a combination of transparent substances, the refracting and dissipating powers of which are different.

In this experiment the rays of mean refrangibility emerge at an angle of refraction equal to $16^{\circ} 57'$.

If a solar ray impinged upon the surface of the prism last applied at an angle of incidence equal to $16^{\circ} 57'$, the angle of dissipation after emergence into air would be equal $12 \frac{1}{4}^{\circ}$.

But it was shewn in the former experiment, that the dissipation of the rays emerging from the two prisms was equal $12 \frac{1}{4}$, for which reason (and on account of the contrary position of the prisms) the red and violet rays emerging, inclined to each other at an angle of $12 \frac{1}{4}$ from the two prisms, and falling upon the third will be refracted out of it colourless.

It appears then that two kinds of glass are necessary for achromatic telescopes, one of which shall possess as small, and the other as great dispersive powers, relatively to their mean refracting ray, as can be procured.

The difference of glass in this respect depends on the quality of the ingredients employed in their composition.

Crown-glass, which is composed of sand, melted

ted by means of the ashes of sea-weeds, barilla, or kelp, both which fluxes are known to consist of vegetable earth, alkali, and neutral salts, is found to give the smallest disperse power.

Plate-glass, which is composed of sand melted by means of fixed alkali, with little or no vegetable earth, gives a greater disperse power.

The disperse power of *flint-glass* is much greater than either of the other, and this consists of sand melted by a mixture of minium and fixed alkali. It is probable therefore, that minium and other metallic calces give the greatest disperse power, and that alkalis give more than vegetable, and probably other earths.

Let a crown-glass prism, whose refracting angle is 30° , be applied contiguous to a prism of flint-glass, whose refracting angle is 19° ; with the vertices of the prisms in opposite directions, a solar ray being refracted through them will deviate from the course of the incident ray, but will not be separated into the coloured rays.

Here it appears, that the two prisms operate equally upon the parallelism of the homogeneous rays passing through them, and that as these effects by the position of the prisms tend to correct each other, the homogeneous rays, after being refracted through them, emerge parallel and colourless.

Mr. Dollond next considered, that as a ray might be refracted free from colour through a wedge, it might also through a lens. When an image of an object is formed by a convex lens, it appears coloured, owing to the dispersion of the rays by refraction; as therefore rays can be refracted without dispersion by prisms, he conceived that it might also be done by a combination of lenses. And in this he succeeded, by considering, that

that in order to make two spherical glasses that should refract the light in contrary directions, as in the two wedges, one must be concave and the other convex; and as the rays are to converge to a real focus, the excess of refraction must be in the convex lens, because that makes rays converge, and the concave makes them diverge. Also, as the convex lens is to refract most, it must be made of crown-glass, as appeared from the experiments with the wedges, and the concave lens of white flint-glass. Farther, as the angle of dispersion varies inversely as the focal length, very nearly, from the principles of optics, and the angle of dispersion also varies as the dispersing powers, therefore if the focal lengths be taken inversely as the dispersing powers, found from the two wedges, the angles of dispersion will be equal, and being in contrary directions they will correct each other, and the different refrangibility of light will be removed.

Upon this principle, Mr. Dollond was enabled to make a combined lens to form an image free from colour, and therefore brought to perfection the refracting telescope, making it represent objects with great distinctness, and in their true colours. Instead of forming the object-glass with one convex lens of crown and one of flint-glass, two convex lenses of crown are used, and the concave one of flint put between them. This construction of the object-glass tends also to correct the error arising from the spherical form of the lens; for as the rays at the edge of the convex lens tend to a focus nearer to the lens than those at the middle, the concave lens, which makes the rays at the edge diverge more than those at the middle, will counteract the above effect, and bring the rays at all distances from the center of the lens to a focus more nearly together; and by a
proper

proper adjustment of the foci, the diffusion of rays at the focus may be rendered inconsiderable. Telescopes thus constructed are called *achromatic*.

This discovery of Mr. DOLLOND was so extraordinary, and so contrary to the best established principles, that it was not believed at first by Mr. EULER. At length, however, Mr. ZICHER, of Petersburg, made experiments similar to those of Mr. Dollond, and convinced Mr. Euler that it was true. He also shewed, that it is the lead which is used in some compositions of glass, which produces the extraordinary property of augmenting the dispersion of the extreme rays, without sensibly changing the refraction of the mean.

Mr. Euler, in a paper read at the academy of sciences at Berlin in 1764, was candid enough to own he did not at first credit the account, and thereby gave to Mr. DOLLOND the credit of the discovery. Notwithstanding this, Mr. Delaland in his astronomy, and Mr. Fieſs in his eulogy on Mr. Euler, both ascribe the invention to Mr. Euler. Mr. P. Dollond has however fully proved, that the discovery must be attributed to Mr. John DOLLOND.*

In the same pamphlet Mr. Dollond has shewn the reasons which prevented Newton from drawing the same conclusions; that it arose from the kind of glass he made use of, so that his veracity remains unimpeached, and the experiments, when made with the same kind of glass, exactly correspond with those of Sir I. Newton. In his time the English were not famous for making telescopes, many were imported from Venice. The glass imported from this place was nearly of the same refractive quality as our crown-glass, but of a better

* "Some account of the discovery by the late Mr. John Dollond, which led to the great improvement of refracting telescopes," by Mr. P. Dollond.

ter colour. It is probable that Newton's prisms were made of that glass, because he mentions the specific gravity of common glass to be to water as 2,58 to 1, which answers nearly to that of crown-glass. Mr. Dollond made a prism of a piece of this glass, and trying the experiment with it, found it answered very nearly to what Newton relates; the difference being only such as may be supposed to arise from the same kind of glass made at different times.

OF REFLECTING TELESCOPES.

Sir John Pringle, in his discourse to the Royal Society on the reflecting telescope, attributes the first thought thereof to Mersennus, who proposed to Descartes a telescope with *specula*, many years before Gregory's invention; though indeed in a manner so very unsatisfactory, that Descartes, who had given particular attention to the improvement of the telescope, was so far from approving the proposal, that he endeavoured to convince Mersennus of the fallacy.

Gregory was led to the invention by seeking to correct two imperfections of the common telescope; the first was, it's too great length, which made it less manageable; the second the incorrectness of the image. It had been demonstrated that a pencil of rays could not be collected in a single point by a spherical lens, and also that the image transmitted by such a lens would be in some degree incurvated.

These inconveniences he believed would be obviated by substituting for the object-glass a metallic speculum of a parabolic figure, to receive the image, and to reflect it towards a small speculum of the same metal; this again was to return the image to an eye-glass placed behind the great speculum,

speculum, which, for that purpose, was to be perforated in it's center.

But as *Gregory* was endowed with no mechanical dexterity, nor could find any workman capable of realizing his invention, after some fruitless attempts he gave up the pursuit. And, probably had not some new discoveries been made in light and colours, a reflecting telescope would never more have been thought of, considering the difficulty of the execution, and the small advantages that could accrue from it, deducible from the principles of optics that were then known.

But *Newton*, whose happy genius for experimental knowledge was equal to that for geometry, and who to these talents, in a supreme degree, joined patience and mechanical abilities, happily interposed and saved this noble invention from well nigh perishing in it's infant state.

While he was employed in endeavouring to grind lenses of the figure of one of the conic sections, he happened to examine the colours formed by a prism, and having by means of that simple instrument made the ever memorable discovery of *the different refrangibility of the rays of light*, he then perceived that the errors of telescopes arising from that circumstance alone, were some hundred times greater than such as were occasioned by the spherical figure of lenses. This forced *Newton* as it were to fall into *Gregory's* track, and to turn his thought to reflectors. If *Newton* was not the first inventor of the reflecting telescope, he was the main and effectual inventor.

It was towards the end of 1668, or the beginning of the following year, that *Newton* being thus obliged to have recourse to reflectors, and not relying on any artificer for making his specula, set about the work himself, and early in the year 1673 completed two small reflecting telescopes; one of these

these he presented to the Royal Society, communicating at the same time a full and satisfactory account of it's construction and performance, and received from them such thanks as were due for so curious and valuable a present.

But how excellent soever the contrivance was, how well soever supported and announced to the public, yet, whether it was that the artists were deterred by the difficulty and labour of the work, or that the discoveries even of a *Newton* were not to be exempted from the general fatality attending great and useful inventions, *the making a slow and vexatious progress to the authors*; the fact is, that excepting an unsuccessful attempt which the Royal Society made by employing an artificer to imitate the Newtonian construction, and a disguised Gregorian telescope, set up by *Cassegrain* abroad, as a rival to *Newton's*, and that in theory only (for it was never put in execution by the author) no reflector was heard of for near half a century after. But when that period was elapsed, a reflecting telescope was produced to the world of the Newtonian construction, which the venerable author, ere yet he had finished his much distinguished course, had the satisfaction to find executed in such a manner, as to leave no room to fear that the invention would longer continue in obscurity.

This memorable event was owing to the dexterity, the genius, and application of Mr. Hadley, the inventor of the reflecting quadrant, another most valuable instrument. The two telescopes which Newton had made, were but 6 inches long, and in power were compared to a 6 feet refractor. Hadley's telescope was above 6 feet long, and equalled in performance the famous aerial telescope of Huygens, of 123 feet in length.*

It

* Sir John Pringle's Discourses, p. 206, &c.

It may be worth observing, that Sir I. Newton sent his telescope to the Royal Society while his election into the society was depending, and he concludes with saying, "that if he should be elected, he would endeavour to testify his gratitude by communicating what his poor and solitary endeavours could effect, toward promoting their philosophical design." Such was the modesty of the man, who was the glory of the society, of the nation, of the world.

OF THE GREGORIAN REFLECTING TELESCOPE.

The Gregorian reflector consists of two concave mirrors, and two plano-convex lenses for the eye-glasses.

TTTT, *fig. 2, pl. 8*, is a cylindrical tube; at the bottom of this a concave metallic reflector or mirror DUVF is placed; this reflector has a hole in the middle.

Towards the other end a small concave mirror L is placed; this is supported on an arm M, which may be moved nearer to, or farther from the great speculum, at pleasure.

These two mirrors are placed parallel to each other; the small one is generally somewhat larger than the hole in the great mirror.

At the bottom of the cylindrical tube, and just opposite to the perforation in the large mirror, is a small brass tube $\alpha\beta\delta\epsilon$, containing the two eye-glasses; at the further end of this tube is a very small hole, to which the eye is to be applied.

The construction being understood, we may proceed to explain the optical effect of this instrument.

1. The open end of the cylindrical tube being set directly towards the object, which being sup-

posed to be distant, the rays proceeding therefrom may be considered as parallel to each other; and being reflected back by the large concave speculum, they will form an image of the object at it's focus, which, from the figure, is evident will be inverted.

Let C represent all the rays proceeding from the point B of the object, and E the pencil of rays proceeding from the point A.

The rays C falling parallel upon the great mirror, will be thence reflected, and converge in the direction DG; and by crossing at I, the principal focus of the mirror, they will form the upper extremity of the inverted image IK, similar to the lower extremity B of the object AB.

In like manner, the rays E, which come from the top of the object, and fall upon the great mirror at F, are thence reflected converging to it's focus, where they form the lower extremity K of the inverted image IK, similar to the upper extremity A of the object AB.

The rays from these two pencils pass on from I and K to the small mirror L, the rays from F falling upon it at h; those from D falling upon it at g, from which points they are again reflected.

2. The focus of the small speculum is at n, a little beyond the place where the image is formed by the great speculum.

If the focus of this mirror fell precisely on m, where the image from the other is formed, the rays would be reflected parallel therefrom; but as it is somewhat beyond or longer than that distance, they are reflected converging in the direction gN.

3. The converging pencil of rays gN, proceeding from the point a, and reflected by the small mirror, would coincide beyond the telescope if they were not refracted by the eye-glasses.

glasses. It is the same with the other converging pencil.

But to render the instrument shorter, these converging rays are made to fall on the lens R in the eye-tube, which increases their convergence, and makes them coincide at a and b, where they form an erect image of the object at a b. This image being at the focus of the lens S, the rays proceeding from the image formed there, are so refracted by it as to emerge parallel to the eye, and thus produce distinct vision.

The light which falls upon the surface of the large mirror is reflected to the small mirror; the eye therefore receives from the telescope a quantity of light, which is to that which it would receive by naked vision, nearly in the same proportion that the surface of the large mirror is to the surface of the small hole at e, near the pupil of the eye.

The rays passing on from the image, pass through the second eye-glass S, and through a small hole e enter the eye f, which sees the image ab, and by means of the eye-glass under the large angle c e d, the second glass increases the field, and renders the image more perfect.

In order to suit different eyes and distances, there is a small rod with a screw at one end; this screw goes through the arm which is fixed to the small reflector, so that by turning the end it brings it nearer, or removes it further from the larger speculum.

An eye-stop is placed at the last image, to cut off the superfluous rays; a very small hole is made at e, to let the rays pass to the eye.

To see near objects, or to accommodate the telescope for long-sighted people, the small mirror must be moved further from the large mirror than when used for distant objects or a common sight; for if

an object comes nearer, i 's image at m will come nearer n , and as nm grows less, nP will grow greater, and will come nearer the lens R ; to reduce or bring it back, the mirror must be removed further.

For *short-sighted people*, the focus P must be brought nearer R , to make the rays more divergent; that is, nP must be longer, and consequently nm shorter, or hg brought nearer to DU , VF .

Therefore for distant objects, and short-sighted people, *turn the screw to the right*; but for near objects and old eyes, *turn to the left*.

This telescope, as you have seen, shews the object erect, but not so bright as in refracting telescopes, because glass transmits more light than metal reflects. It has been estimated, that one third of the light received is lost by reflection.

The *visible area* of an object is as the breadth of the eye-glass; for if the image at IK , and the eye-glass be increased, the image at m will also be increased, because the angles of incidence and reflection at hg are equal, and consequently the visible part of the object is increased.

The brightness of the object is in proportion to the aperture, for the larger this is, the greater is the quantity of light that comes to the eye.

The extreme parts of the image are less bright than the rest, because the shadow of the small speculum falls on the outside, but towards the middle it only covers the hole.

To render the determination of the magnifying power more easy, I shall consider the tube to be twelve inches long, two inches diameter; the concave speculum, at the bottom of the tube, to be of seven inches focus, and two inches diameter; the

the hole in the center $\frac{5}{12}$ of an inch in diameter; the focus of the small mirror $\frac{18}{12}$, it's diameter $\frac{9}{12}$ of an inch; the first eye-glass about three inches focus, the second about $\frac{10}{12}$. We must now refer back to our former instructions on the principles of rays of light, when reflected from a spherical concave mirror.

You will recollect, 1st, That the light, which comes from a very distant object, is so reflected that the point where they meet, and where the image is formed, is $\frac{1}{4}$ part of the diameter of the sphere, of which the great speculum is a segment. 2d, That if the object is at the focus of a concave spherical mirror, the rays falling therefrom are reflected parallel to each other.

Now distant objects seen through the reflecting telescope, form an inverted image at I K, the focal point of the large speculum, and nine inches therefrom, and the image and object both appear under the same angle from the vertex of the mirror; this image at the focus I K being the base of two angles, whose summits are the centers of the two spherical mirrors. Now the distance of the focus of the two mirrors is as $1\frac{1}{2}$ to 9, or as 3 to 18, by taking away the fraction; or as 1 to 6, by dividing the terms by 3: therefore the two angles are in the proportion of 1 to 6, that is, the angle subtended by the spherical surface, of which A B is a portion, is six times larger than what the object subtends at the surface of the larger mirror; consequently if the eye was placed in the parallel rays proceeding from the small speculum, it would see the object perfectly therein, and magnified in the proportion of the focal distances of the two metals, that is, as 6 to 1.

Now the two lenses in the eye-tube form a telescope, whose property, on the principles al-

ready laid down, is to magnify the object in the proportion that the focus of the lens S exceeds that of R in this instance, as 36 to 10; but the telescope was before shewn to magnify in the proportion of 6 to 1. By combining these proportions, we shall obtain 10×1 , and 36×6 , or 10 to 216, or nearly as 1 to 22.

OF THE NEWTONIAN TELESCOPE.

The telescope of *Newton* differs a little in the construction from that of *Gregory*, but it is founded upon the same principles, as well geometrical as physical.

It consists, like the former, of a tube to receive the metals; the upper end of the tube is open; at the bottom of this is placed a *concave metal reflector*, and a *plain small metal reflector*, inclined 45 degrees to the axis of the large reflector. This small reflector must be of an oval form; the length of the oval should be to the breadth as 2 to 1, on account of the obliquity of it's position; it is supported on an arm fixed to the side of the tube; an eye-glass is placed in a small tube, moveable in the larger tube, so as to be perpendicular to the axis of the large reflector, the perpendicular line passing through the center of the small mirror. The small mirror is to be situated between the large mirror and it's focus, that it's distance from this focal point may be equal to the distance from the center of the mirror to the focus of the eye-glass.

The tube *v x z y*, *fig. 3, pl. 8*, being turned with it's open end towards the object, parallel rays coming therefrom will be reflected by the concave mirror to it's focus, where it would form an inverted
image

image of the object, but from the interposition of the small reflector *f* *e* *g*, they are prevented coming to the focus, and are reflected to *t*, the focus of the eye-glass, where they form an image equal to what would have been formed at the focus of the concave mirror. This image being in the focus of the eye-glass, the rays proceeding therefrom will be so refracted by the lens, as to emerge parallel to the eye, and therefore properly constituted to produce distinct vision.

If the face be turned towards the open end of the tube, and the eye be applied at *h*, the object will appear inverted; but if the face be turned towards *c* *d*, the object will be erect: the latter position is in most cases very inconvenient.

The magnifying power is in the same proportion as the focal distance of the concave speculum exceeds that of the eye-glass. This telescope will bear a greater aperture than the Gregorian reflector; less light is also lost from the oval plane, than from a spherical reflector. It is by means of a Newtonian telescope that Dr. Herschel has added so many valuable discoveries to astronomy.

There is another kind of reflecting telescope, known by the name of Cassegrain; but as it is not used at present, it will be needless for me to describe it here; I shall therefore only observe, that it is similar to the Gregorian telescope, except in one instance, namely, that the small speculum is convex instead of concave.

The disadvantages under which reflecting telescopes labour, arise from their requiring larger apertures to transmit the same quantity of light; from being more affected by the imperfections of the atmosphere than a refracting telescope; from being liable to tarnish; but principally from the imperfections of the workmanship of the object-spe-

culum, which injures them more than equal faults in the object-glass of refractors.

In the hands of a man whose mind is well directed, every part of science is made useful; among many instances of this, I shall give you one from the learned Mr. Jacob Bryant's treatise on the Authenticity of the Scriptures, in which, from the telescopes we have been considering, he shews the weakness of some infidel objections to revelation. Thus he shews, that there is no more reason to object to the authenticity of the scriptures on account of some difficulties, than to natural religion or natural philosophy on the same account; for they are equally attended with difficulties. Natural philosophy abounds with phenomena which we see and know, but cannot explain, as gravity, magnetism, &c.

If any person had prophetically informed *Archimedes* or *Eudoxus*, that vision would one day be wonderfully assisted by art, and that the manner of improving sight would be to place a *dark opaque substance* directly between the object and the eye, they must have thought the prophet out of his senses. And when they heard that the other method was, in viewing an object, *not to look at it*, but to keep the eye in a quite different direction, how could they digest these doctrines, by which they were taught, that sight would be helped by impediments, and that the best way of seeing objects was looking another way?

Yet whoever is acquainted with the *Gregorian telescope*, must know, that such a *dark body* does intervene between the eye and the object; and that in the *Newtonian telescope* the sight is directed sideways, at an angle of 90 degrees. When once known, the thing is found to be consonant to reason and experience.

If

If then we meet with many things in common life and worldly science, which seem difficult to comprehend, and some beyond our reason, we must expect to find others beyond our reason in that grand system of life and immortality laid before us in holy writ.

LECTURE XXIII.

OF MICROSCOPES.

* **B**Y a microscope we understand *an instrument for viewing small objects*, rendering those visible which would ~~be otherwise~~ imperceptible. Microscopes are divided into three different kinds, *single, compound, and solar*; *single* microscopes are those which consist of one lens; *compound*, those which are formed of two or more lenses; *solar*, those which are used in a dark room, the object being illuminated by the sun, and the image received on a screen.

It is generally supposed, that microscopes were invented about the year 1680, a period fruitful in discoveries, when the mind began to emancipate itself from those errors and prejudices by which it had been too long enslaved, to assert it's rights, extend it's powers, and follow the paths which lead to truth. The honour of the invention is claimed by the Italians and the Dutch; the name of the inventor, however, is lost; probably the discovery did not at first appear sufficiently important, to engage the attention of those men, who, by their reputation in science, were able to establish an opinion of it's merit with the rest of the world, and hand down the name of the inventor to succeeding

* See my Essays on the Microscope, of which I mean to publish a new edition the same size with this work, to which it will be a proper supplement, manifesting the wisdom of God in the minute parts of creation,

ucceeding ages. Men of great literary abilities are apt to despise the first dawnings of invention, not considering that all real knowledge is progressive, and that what they deem trifling may be the first and necessary link to a new branch of science.

The microscope extends the boundaries of the organs of vision; enables us to examine the structure of plants and animals; presents to the eye myriads of beings, of whose existence we had before formed no idea; opens to the curious an exhaustless source of information and pleasure; and furnishes the philosopher with an unlimited field of investigation. It leads, to use the words of an ingenious writer, to the discovery of a thousand wonders in the works of his hand, who created ourselves, as well as the objects of our admiration; it improves the faculties, exalts the comprehension, and multiplies the inlets to happiness; is a new source of praise to him, to whom all we pay is nothing of what we owe; and while it pleases the imagination with the unbounded treasures it offers to the view, it tends to make the whole life one continued act of admiration. For there is no object so inconsiderable, that it has not something to invite the curious eye to examine it; nor is there any, which, when properly examined, will not amply repay the trouble of investigation.

It is not difficult to fix the period when the microscope first began to be generally known, and was used for the purpose of examining minute objects; for though we are ignorant of the name of the first inventor, we are acquainted with the names of those who first engaged the public attention, by exhibiting some of its wonderful effects. Zacharias Jansens and his son had made microscopes before the year 1619, for in that year the ingenious Cornelius Drebell brought one, which was made
by

by them, with him into England, and shewed it to William Borrell and others. It is possible this instrument of Drebell's was not strictly what is now meant by a microscope, but was rather a kind of microscopic telescope, something similar in principle to that lately described by Mr. Aepinus, in a letter to the Academy of Sciences at Petersburg. It was formed of a copper tube six feet long and one inch diameter, supported by three brass pillars in the shape of dolphins; these were fixed to a base of ebony, on which the objects to be viewed by the microscope were also placed. In contradiction to this, Fontana, in a work which he published in 1646, says, that he had made microscopes in the year 1618: this may be also very true, without derogating from the merit of the Jansens, for we have many instances in our own times of more than one person having executed the same contrivance, nearly at the same time, without any communication from one to the other. In 1685, Stelluti published a description of the parts of a bee, which he had examined with a microscope.

If we consider the microscope as an instrument consisting of one lens only, it is not at all improbable, that it was known to the ancients much sooner than the last century, nay, even in a degree to the Greeks and Romans; for it is certain, that spectacles were in use long before the above-mentioned period. Now as the glasses of these were made of different convexities, and consequently of different magnifying powers; it is natural to suppose, that smaller and more convex lenses were made, and applied to the examination of minute objects. In this sense, there is also some ground for thinking the ancients were not ignorant of the use of lenses, or at least of what approached nearly to, and might in some instances be substituted for them.

OF THE OPTICAL EFFECT OF MICROSCOPES.

It has been already observed, that the human eye is so constituted, that we cannot see an object distinctly when it is nearer the eye than six inches. To enable us to see objects nearer is the design of microscopes, for by this means we are enabled to discern those objects which, from their minuteness, become imperceptible at a small distance. Hence a microscope is said to magnify the objects seen through it; but this expression is only true with respect to the *apparent* magnitude of the object.

To have right ideas on this subject, you must distinguish the apparent from the real magnitude of objects; the real magnitude of an object is the object of geometry, and remains *invariable* as long as the object continues in the same state; the apparent magnitude may be *infinitely varied*, while the real size remains unaltered. Thus the stars in the heavens appear to us exceeding small, although their real size is prodigious; this difference is occasioned by their immense distance. If we could approach them, we should find them increase in size as the distance diminishes; the apparent magnitude depending in a great degree on the angle under which it is seen, and this angle increases or diminishes, according as the object is nearer to or further from the eye.

Thus let POQ , *fig. 4, pl. 8*, be the object of our sight; this, if the eye be at A , will appear under the angle PAQ , called the *visual angle*, and which determines in a great measure the apparent size of an object. It is plain from hence, that the further the eye is from the object, the smaller is this angle; and that thus the largest bodies may be seen under an exceeding small angle, if they are at a sufficient distance.

If

If the eye be at B, the object will be seen under the angle OBQ , which is visibly larger than the angle PAQ . Let the eye be at c, the angle PCQ is larger than PBQ ; and so on, the nearer the eye is to the object, the larger is the visual angle.

From hence it follows, that the apparent diameter of an object seen by the naked eye, may be magnified in any proportion we please; for as the apparent diameter is increased in proportion as the distance from the eye is lessened, we have only to lessen the distance of the object from the eye, in order to increase the apparent diameter thereof.* Thus, suppose there is an object, AB , *pl. 8, fig. 5*, which to an eye at E subtends or appears under the angle AEB , we may magnify the apparent diameter in what proportion we please, by bringing our eye nearer to it. If, for instance, we would magnify it in the proportion of FG to AB ; that is, if we would see the object under an angle as large as $FE G$, or would make it appear the same length that an object as long as FG would appear, it may be done by coming nearer to the object. For the apparent diameter is as the distance inversely; therefore, if CD is as much less than CE , as FG is greater than AB , by bringing the eye nearer to the object in the proportion of CD to ED , the apparent diameter will be magnified in the proportion of FG to AB ; so that the object AB , to the eye at D , will appear as long as an object FG would appear to the eye at E . In the same manner, we might shew, that the apparent diameter of an object, when seen by the naked eye, may be infinite. For since the apparent diameter is reciprocally as the distance of the eye, when the distance of the eye is nothing, or when the eye is close

* Rutherford's System of Natural Philosophy, p. 330.

close to the object at C, the apparent diameter will be the reciprocal of nothing, or infinite.

There is, however, one great inconvenience in thus magnifying an object, without the help of glasses, by placing the eye nearer to it. The inconvenience is, that we cannot see an object distinctly, unless the eye is about five or six inches from it; therefore, if we bring it nearer to our eye than five or six inches, however it may be magnified, it will be seen confusedly. Upon this account, the greatest apparent magnitude of an object that we are used to, is the apparent magnitude when the eye is about five or six inches from it: and we never place an object much within that distance; because, though it might be magnified by this means, yet the confusion would prevent our deriving any advantage from seeing it so large. The size of an object seems extraordinary, when viewed through a convex lens; not because it is impossible to make it appear of the same size to the naked eye, but because at the distance from the eye which would be necessary for this purpose, it would appear exceedingly confused; for which reason, we never bring our eye so near to it, and consequently as we have not been accustomed to see the object of this size, it appears an extraordinary one.

On account of the extreme minuteness of the atoms of light, it is clear, a single ray, or even a small number of rays, cannot make a sensible impression on the organ of sight, whose fibres are very gross, when compared to these atoms; it is necessary, therefore, that a great number should proceed from the surface of an object, to render it visible. But as the rays of light, which proceed from an object, are continually diverging, different methods have been contrived, as we have already shewn

shewn you, either of uniting them in a given point, or of separating them at pleasure.

Thus, by the help of convex lenses, we unite in the same sensible point a great number of rays, proceeding from one point of an object; and as each ray carries with it the image of the point from whence it proceeded, all the rays united must form an image of the object from whence they were emitted. This image is brighter, in proportion as there are more rays united; and more distinct, in proportion as the order in which they proceeded, is better preserved in their union.

We perceive the presence and figure of objects by the impression each respective image makes on the retina; the mind, in consequence of these impressions, forms conclusions concerning the size, position, and motion of the object. It must however be observed; that these conclusions are often rectified or changed by the mind, in consequence of the effects of more habitual impressions. For example; there is a certain distance, at which, in the general business of life, we are accustomed to see objects: now, though the measure of the image of these objects changes considerably when they move from, or approach nearer to us, yet we do not perceive that their size is much altered: but beyond this distance, we find the objects appear to be diminished, or increased, in proportion as they are more or less distant from us.

For instance, if I place my eye successively at two, at four, and at six feet from the same person, the dimensions of the image on the retina will be nearly in the proportion of 1, of $\frac{1}{2}$, of $\frac{2}{3}$, and consequently they should appear to be diminished in the same proportion; but we do not perceive this diminution, because the mind has rectified the impression

pression received on the retina. To prove this, we need only consider, that if we see a person at 120 feet distance, he will not appear so strikingly small, as if the same person should be viewed from the top of a tower, or other building, 120 feet high, a situation to which we had not been accustomed.

From hence, also, it is clear, that when we place a glass between the object and the eye, which from it's figure changes the direction of the rays of light from the object, this object ought not to be judged as if it were placed at the ordinary reach of the sight, in which case we judge of it's size more by habit than by the dimensions of the images formed on the retina: but it must be estimated by the size of the image in the eye, or by the angle formed at the eye, by the two rays which come from the extremity of the object.

If the image of an object, formed after refraction, is greater or less than the angle formed at the eye, by the rays proceeding from the extremities of the object itself, the object will appear also proportionably enlarged or diminished; so that if the eye approaches to, or removes from, the last image, the object will appear to increase or diminish, though the eye should in reality remove from it in one case, or approach towards it in the other; because the image takes place of the object, and is considered instead of it.

The apparent distance of an object from the eye, is not measured by the real distance from the last image; for, as the apparent distance is estimated principally by the ideas we have of their size, it follows, that when we see objects, whose images are increased or diminished by refraction, we naturally judge them to be nearer or further from the eye, in proportion to the size thereof,

when compared to that with which we are acquainted. The apparent distance of an object is considerably affected by the brightness, distinctness, and magnitude thereof. Now as these circumstances are, in a certain degree, altered by the refraction of the rays in their passing through different media, they will also, in some measure, affect the estimation of the apparent distance.

OF THE SINGLE MICROSCOPE.

The single microscope renders minute objects visible, by means of a small glass globule, or convex lens, of a short focus. Let E Y, *fig. 6, pl. 8*, represent the eye; and O B, a small object situated very near to it, consequently the angle of it's apparent magnitude very large. Let the convex lens R S be interposed between the eye and the object, so that the distance between it and the object may be equal to the focal length; and the rays which diverge from the object, and pass through the lens, will afterwards proceed, and consequently enter the eye parallel: after which, they will be converged, and form an inverted image on the retina, and the object will be clearly seen; though, if removed to the distance of six inches, it's smallness would render it invisible.

When the lens is not held close to the eye, the object is somewhat more magnified; because the pencils, which pass at a distance from the center of the lens, are refracted inward towards the axis, and consequently seem to come from points more remote from the center of the object.

Fig. 10, pl. 8, may, perhaps, give the reader a still clearer view, why a convex lens increases the angle of vision. Without a lens, as F G, the eye
at

at A would see the dart BC under the angle bAc ; but the rays BF and CG from the extremities of the dart in passing through the lens, are refracted to the eye in the directions fA and Ga, which causes the dart to be seen under the much larger angle DAE (the same as the angle fAg). And therefore, the dart BC will appear so much magnified, as to extend in length from D to E.

The object, when thus seen distinctly, by means of the small lens, appears to be magnified nearly in the proportion which the focal distance of the glass bears to the distance of the objects, when viewed by the naked eye.

To explain this further, place the eye close to the glass, that as much of the object may be seen at one view as is possible; then remove the object to and fro, till it appears perfectly distinct, and well defined; now remove the lens, and substitute in it's place a thin plate, with a very small hole in it, and the object will appear as distinct, and as much magnified, as with the lens, though not quite so bright; and it appears as much more magnified in this case, than it does when viewed with the naked eye, as the distance of the object from the hole, or lens, is less than the distance at which it may be seen distinctly with the naked eye.

From hence we see, that the whole effect of the lens or microscope is to render the object distinct, which it does by assisting the eye to increase the refraction of the rays in each pencil; and that the apparent magnitude is entirely owing to the object being seen so much nearer the eye than it could be viewed without it.

In other words, a single microscope removes the confusion that accompanies objects when seen very near the eye, while it leaves the visual angle the same. 1. It removes the confusion, for the

object being placed in the focus of the lens, the rays emerging from thence are parallel, which you know is necessary to distinct vision. 2. The angle is the same, for whether the eye touches the glass, or is removed a little way from it, it appears under the same angle as it would to the eye placed where the glass is fixed.

Single microscopes magnify the diameter of the object, as we have already shewn, in the proportion of the focal distance (to the limits of distinct vision with the naked eye) to eight inches. For example, if the semi-diameter of a lens, equally convex on both sides, be half an inch, which is also equal to it's focal distance, we shall have as $\frac{1}{2}$ is to 8, so is 1 to 16; that is, the diameter of the object in the proportion of sixteen to one. As the distance of eight inches is always the same, it follows, that by how much the focal distance is smaller, there will be a greater difference between it and the eight inches; and consequently, the diameter of the object will be so much the more magnified, in proportion as the lenses are segments of smaller spheres.

As the closer the object is to the eye the larger it appears, it follows, that a double and equally convex lens is preferable to a plano-convex lens, because with equal convexities the focal length of the former is only half as long as the latter. Now as the double convex consists of two segments of a sphere, the more an object is to be magnified, the greater must be the convexity, and therefore the smaller the sphere, till at last the utmost degree of magnifying power will require that these segments become hemispheres, and consequently the lens will be reduced to a perfect spherule, or very small sphere.

Very extraordinary magnifying powers may be obtained by means of small spherules, for the
focus

focus of parallel rays is only half the radius distant from the spherule; therefore, if the radius of the spherule be $\frac{1}{16}$ of an inch, the eye will have distinct vision of an object by means thereof at the distance of a radius and a half, i. e. $\frac{3}{2}$ of an inch, which is but the fortieth part of 6 inches, so that the length of an object will be magnified 40 times, the surface 1600.

OF THE DOUBLE OR COMPOUND MICROSCOPE.

In the compound microscope, the image is viewed instead of the object, which image is magnified by a single lens, as the object is in a single microscope. It consists of an object lens, LN, *fig. 8, pl. 8*, and an eye-glass FG. The object OB is placed a little further from the lens than it's principal focal distance, so that the pencils of rays proceeding from the different points of the object through the lens, may converge to their respective foci, and form an inverted image of the object at PQ; which image is viewed by the eye through the eye-glass FG, which is so placed, that the image may be in it's focus on one side, and the eye at the same distance on the other. The rays of each pencil will be parallel, after passing out of the glass, till they reach the eye at E, where they will begin to converge by the refractive powers of the humours; and after having crossed each other in the pupil, and passed through the crystalline and vitreous humours, they will be collected in points on the retina, and form a large inverted image thereon.

It will be easy, from what has been already explained, to understand the reason of the magnifying power of a compound microscope. The object is magnified upon two accounts; first, because if we viewed the image with the naked eye,

it would appear as much larger than the object, as the image is really larger than it, or as the distance fR is greater than the distance fb ; and secondly, because this picture is again magnified by the eye-glass, upon the principle explained in the foregoing article on vision by single microscopes.

But it is to be noted, that the image formed in the focus of a lens, as is the case in the compound microscope, differs from the real object in a very essential particular; that is to say, the light being emitted from the object in every direction, renders it visible to an eye placed in any position; but the points of the image formed by a lens, emitting no more than a small conical body of rays, which arrives from the glass, can be visible only when the eye is situated within its confine. Thus the pencil, which emanates from O in the object, and is converged by the lens to D , proceeds afterwards diverging towards H , and therefore never arrives at the lens FG , nor enters the eye at E . But the pencils which proceed from the points o and b , will be received on the lens FG , and by it carried parallel to the eye; consequently, the correspondent points of the image QP will be visible; and those which are situated farther out towards H and I , will not be seen. This quantity of the image QP , or visible area, is called the field of view.

Hence it appears, that if the image be large, a very small part of it will be visible; because the pencils of rays will for the most part fall without the eye-glass FG . And it is likewise plain, that a remedy which would cause the pencils, which proceed from the extremes O and B of the object, to arrive at the eye, will render a greater part of it visible; or, in other words, enlarge the field of view. This is effected by the interposition of a broad lens DE of a proper curvature, at a
small

small distance from the focal image. For, by that means, the pencil DM, which would otherwise have proceeded towards H, is refracted to the eye as delineated in the figure, and the mind conceives from thence the existence of a radiant point at Q, from which the rays last proceeded. In like manner, and by a parity of reason, the other extreme of the image is seen at P, and the intermediate points are also rendered visible. On these considerations it is, that compound microscopes are usually made to consist of an object lens LN, by which the image is formed, enlarged, and inverted; an amplifying lens DE, by which the field of view is enlarged, and an eye-glass or lens, by means of which the eye is allowed to approach very near, and consequently to view the image under a very great angle of apparent magnitude. It is now customary to combine two or more lenses together at the eye-glass, in the manner of Eustachio Divini and M. Joblot; by which means, the aberration of light from the figure is in some measure corrected, and the apparent field increased.

OF THE SOLAR MICROSCOPE.

In this instrument, the image of the object is thrown upon a screen in a darkened room. It may be considered under two distinct heads: 1st, the mirror and lens, which are intended to reflect the light of the sun upon the object; and 2dly, that part which constitutes the microscope, or which produces the magnified image of the object, *fig. 9, pl. 8*. Let NO represent the side of a darkened chamber; GH a small convex lens, fixed opposite to a perforation in the side NO; AB a plane mirror, or looking-glass, placed without the room to reflect the solar rays a, b, c, &c. on the lens CD, by which

they are converged and concentrated on the object fixed at E F.

2. The object being thus illuminated, the ray which proceeds from E will be converged by the lens G H to a focus K, on the screen L M; and the ray which comes from F will be converged to I, and the intermediate points will be delineated between I and K; thus forming a picture, which will be as much larger than the object, in proportion as the distance of the screen exceeds that of the image from the object.

GENERAL OBSERVATIONS.

From what has been said, it appears plainly, the advantages we gain by microscopes are derived, first, from their magnifying power, by which the eye is enabled to view more distinctly the parts of minute objects: secondly, that by their assistance, more light is thrown into the pupil of the eye, than is done without them. The advantages procured by the magnifying power, would be exceedingly circumscribed, if they were not accompanied by the latter: for if the same quantity of light is diffused over a much larger surface, it's force is proportionably diminished; and therefore the object, though magnified, will be dark and obscure. Thus, suppose the diameter of the object to be enlarged ten times, and consequently the surface one hundred times, yet, if the focal distance of the glass was eight inches, (provided this was possible) and it's diameter only about the size of the pupil of the eye, the object would appear one hundred times more obscure when viewed through the glass, than when it was seen by the naked eye; and this even on the supposition, that the glass transmitted all the light which fell upon it, which no glass can do,

do. But if the glass was only four inches focal distance, and it's diameter remained as before, the inconvenience would be vastly diminished; because the glass could be placed twice as near the object as before, and would consequently receive four times as many rays as in the former case, and we should therefore see it much brighter than before. By going on thus, diminishing the focal distance of the glass, and keeping it's diameter as large as possible, we shall perceive the object proportionably magnified, and yet remain bright and distinct. Though this is the case in theory, yet there is a limit in optical instruments, which is soon arrived at, but which cannot be passed. This arises from the following circumstances.*

1. The quantity of light lost in passing through the glass.

2. The diminution in the diameter of the glass or lens itself, by which it receives only a small quantity of rays.

3. The extreme shortness of the focal distance of great magnifiers, whereby the free access of the light to the object we wish to view is impeded, and consequently the reflection of the light from it is weakened.

4. The aberration of the rays, occasioned by their different refrangibility.

To make this more clear, let us suppose a lens made of such dull kind of glass, that it transmits only one half the light that falls upon it. It is evident, that supposing this lens to be of four inches focus, and to magnify the diameter of the object twice, and it's own breadth equal to that of the pupil of the eye, the object will be four times magnified in surface, but only half as bright as if it was seen by the naked eye at the usual distance;
for

* Encyclopedia Britannica, vol. viii. p. 5635.

for the light which falls upon the eye from the object at eight inches distance, and likewise the surface of the object in it's natural size, being both represented by 1, the surface of the magnified object will be 4, and the light which makes it visible only 2; because though the glass receives four times as much light as the naked eye does at the usual distance of distinct vision, yet one half is lost in passing through the glass. The inconvenience, in this respect, can only be removed so far as it is possible to increase the transparency of the glass, that it may transmit nearly all the rays which fall upon it; and how far this can be done, has not been yet ascertained.

The second obstacle to the perfection of microscopic glasses, is the small size of great magnifiers; by which means, notwithstanding their near approach to the object, they receive a smaller quantity of light than might be expected. Thus, suppose a glass of only one-tenth of an inch focal distance, such a glass would increase the visible diameter eighty times, and the surface 6400 times. If the breadth of the glass could at the same time be preserved as great as the pupil of the eye, which we shall suppose one-tenth of an inch, the object would appear magnified 6400 times, and every part would be as bright as it appears to the naked eye. But if we suppose the lens to be only $\frac{1}{20}$ of an inch diameter, it will then only receive $\frac{1}{4}$ of the light which would otherwise have fallen upon it; therefore, instead of communicating to the magnified object a quantity of light equal to 6400, it would communicate an illumination suited only to 1600, and the magnified object would appear four times as dim as it does to the naked eye. This inconvenience can, however, be in a great degree removed, by throwing a much larger quantity of light on the object.

The

The third obstacle arises from the shortness of the focal distance in large magnifiers; this inconvenience can, like the former, be remedied in some degree by artificial means of accumulating light; but still the eye is so strained, as it must be brought nearer the glass than it can well bear, which in some measure supersedes the use of very deep lenses, or such as are capable of magnifying beyond a certain degree.

The fourth obstacle arises from the different refrangibility of the rays of light, and which frequently causes such deviations from truth in the appearance of things, that many have imagined themselves to have made surprizing discoveries, and have communicated them as such to the world; when, in fact, they have been only optical deceptions, owing to the unequal refraction of the rays.

CONCLUSION.

After all that has been said on optics, &c. the question still occurs, *What is light? how is it formed? and of what substance?* These are questions that have been canvassed and disputed since the first origin of science and philosophy; and numberless are the conjectures which at different periods have arisen concerning them in the schools of learning.

Empedocles, one of the earliest philosophers of Greece, taught that light was an emanation of certain luminous atoms, subtil enough to pervade the invisible pores of air, water, and other diaphanous bodies. Plato seems to have been, in every material circumstance, of the same opinion; and

and further maintained, that colour is no more than an extremely rare and subtil flame, capable of penetrating the densest bodies. Empedocles accounted for vision in a two-fold way, that it was performed by the effluvia which proceed from the object, and by the emission of light from the eye, as from a lanthorn. The latter opinion is proved, by a passage cited by Aristotle; it is a beautiful remains of antiquity. I shall give it you from Sydenham's translation:

As when the trav'ler in dark winter's night,
Intent on journey, kindles up a light,
The moon, like splendor of an oil-fed flame,
He sets it in some lantern's horny frame;
Calm and serene there sits the tender form,
Screen'd from rough winds, and from the wintry storm.
In vain rude airs assault the gentle fire,
Their forces break, disperse, and they retire;
Fences secure, tho' thin, the fair inclose,
And her bright head she lifts amidst her foes.
Thro' the strait pores of the transparent horn,
She shoots her radiance, mild as early morn.
Forth fly the rays; their shining path extends,
Till lost in the wide air, their less'ning lustre ends.
So when the fire fresh lighted from on high,
Sits in the circling pupil of an eye;
O'er it, transparent veils of fabric fine
Spread the thin membrane, and defend the shrine;
The subtil flame inclosing like a mound,
Safe from the flood of humours flowing round.
Forth fly the rays, and their bright paths extend,
Till, in the wide air lost, their lustres end.*

* Nor is this reasoning of the ancients to be altogether despised, for there are various arguments and experiments to prove that the seat of sense is not entirely passive in receiving images, but that it also directs a ray from itself, to every object it perceives. The action and re-action between objects and the seat of sense is wholly reciprocal." A. Wilson, M. D. *Medical Researches*.

Descartes

Descartes maintained, that light, as it existed in the luminous body, is nothing but a power or faculty of exciting in us a very clear and vivid sensation; and that the invifible pores of lucid bodies are pervaded by a subtil and highly elastic matter, capable of being impelled by these bodies, and of producing on the organs of vision, when properly formed, the perception of light.

Sir Ifaac Newton seems to have formed no direct opinion on the subject; from what he has said we may conclude, he thought it consisted of solid particles of matter, when explaining more particularly the nature of light, he says, that it is refracted and reflected by an ethereal medium, by the vibrations of which, it communicates heat to bodies, and is put into fits of easy reflection and transmission.

In the peripatetic school, light was considered as a substance, neither purely spiritual nor purely corporeal, and was therefore defined a *materia media*; and indeed, when we contemplate, with a philosophic eye, the astonishing effects of light, we find sufficient ground for accounting it of a nature widely different from lumpish, gross, inactive matter. That light, however, is material, cannot, as we have already shewed you, be disputed with any degree of probability. The materiality not only appears from it's being propagated in time, but from it's not bending into shadow. The solar rays are not only capable of being collected by a burning-glass, but when collected, exhibit marks of a power altogether irresistible. If a diamond, the hardest of terreous bodies, be placed in the focus of a burning-glass, the light immediately enters it, tears it's parts asunder, divides and dissolves them. Here you perceive the lens acting upon the light, and the light upon the diamond. Since, therefore, light
both

both acts and is acted upon, as matter, we must allow it's properties to be material.

The unparalleled subtilty of light, and the impossibility of subjecting it to chemical analysis, render every inquiry into it's essence peculiarly arduous and difficult. Many and various are the phenomena which point out the most intimate and immediate connection between fire and light. You all know, that those bodies which are heated most intensely, are most luminous, and that the light of the sun concentrated by convex glasses, produces a degree of heat almost irresistible. Here you perceive, that fire produces light, and light produces the most intense heat. If, therefore, the same causes produce the same effects, or, inverting the axiom, if the same effects proceed from the same causes, it must be inferred in the present instance, that light and fire are either one and the same substance, or at least in the immediate chain of cause and effect.

The connection between fire and light is further evinced by the well-known effects of the latter on most bodies; innumerable experiments shew, that there is a certain degree of heat at which bodies become luminous, and that all bodies which sustain that heat, without being converted into vapour, may universally be ignited. There are even some substances, which, though they evaporate at a degree of heat far below that at which they should begin to shine, may, by proper management, be ignited.

It now, I think, appears, that when Plato defined light "a rare and subtil flame," he came nearer the truth than later philosophers have in general imagined. Can you desire a more convincing proof of the solid judgment and penetration of that ancient sage, than that after the lapse of so many centuries, and the vast progress made in
the

the science of nature, we are under the necessity of rejecting the theories of the moderns, to revive his long exploded doctrine, as most consonant with facts and experiments. For, if to the arguments already used to prove the identity of fire and light, it be added, that light and heat diffuse themselves from a center outward, that they act in strait lines, and are subject to the same laws of reflection, we can hardly withhold our assent from the Platonic doctrine.

It may be further observed, that in general no light is excited until a decomposition takes place, and the fixed, or latent fire, begins to be separated from the bodies: light may be therefore considered as fire passing through certain strainers well defined, and as existing in a more pure and simple state, and being less incumbered with terreous gravitating matter, than fire.

And if you survey the various operations of nature, with that attention and accuracy that are necessary in the prosecution of physical inquiries, I think I may venture to assert, that you will not meet with a single instance from which it can appear, that light can be excited without the concurrence of the elementary principle of fire.

I have now finished another set of Lectures, and have given you an account of the known properties of light, and among many other things have explained to you the wonderful mechanism of the eye, whereby it is rendered the means of vision; and shewn you what assistance it receives from glasses. It has here also been shewn you, that the particles, of which light is composed, are of different colours, and that the colour of each particle is lasting and permanent, so as not to be changed either by refraction or reflection; and that those particles which differ as to colour, differ

also as to refrangibility; and that light, by being thus differently coloured, dresses nature in various beauties. In these Lectures I have explained to you the principles of the microscope and telescope, instruments, by which the boundaries of human knowledge have been much enlarged. In this set of Lectures there are further proofs, that "*air, fire, and light*, are the powers in nature by which all natural motion and life are preserved: the most ignorant are sensible of this truth, and it cannot be contradicted by the most learned."

From the discoveries laid before you in these Lectures, it is evident, "that the works of creation are infinitely more glorious than they appear to be; that they are seen by us under those circumstances and disadvantages which obscure their true character and intrinsic splendor; that in proportion as our attention is fixed upon them, their lustre brightens, their excellencies become more conspicuous."*

I have occasionally pointed out to you the application of light as a significant emblem in the sacred writings, in which the material elements of a visible world are always used to lead you to the knowledge of one that is spiritual and invisible. By due attention to these, you will be able to perceive the energies of the *Divine Mind* in all the various forms of outward nature, and acknowledge that God alone is the beauty and benefit of all his works; that, as they cannot exist but IN HIM and BY HIM, so HIS impression is upon them, and HIS impregnation through them.

Though the elements have a mixture of natural and physical evil, yet *divine order* influences throughout, and is an internal principle of good, which is alone all the beauty and beneficence, the whole

* Gray's Sermons, p. 9.

whole glory and graciousness that is in them; nor can they possibly exhibit any beauty or amiableness but what they derive from God. All things animate and inanimate co-operate in displaying his wisdom and power; all unite in the universal song to the glory and praise of their beneficent CREATOR.

“ Air uttering tells *his harmony* in sounds;
The light reveals the *fountain* of it's rays,
And like the seraph kindles in his praise.
———All echoing the SUPREME's design,
BEAUTY OF LOVE, and SYMMETRY DIVINE!”

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whole glory and grandeur that is in them; nor
 can they possibly exhibit any beauty or amiable-
 ness but what is derived from God. All things
 exist and subsist in dependence on him, and
 his wisdom and power are manifest in the universal
 order and beauty of his creation.

And thus we see the wisdom and power of God
 manifest in the universal order and beauty of his
 creation. And thus we see the wisdom and power of
 God manifest in the universal order and beauty of
 his creation.

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Fig. 3, p. 181.	Fig. 9, p. 184.	Fig. 14, p. 191.
Fig. 4, p. 182.	Fig. 10, p. 208.	Fig. 15, p. 192.
Fig. 5, p. 226.	Fig. 11, p. 189.	Fig. 15,* p. 194.
Fig. 6, p. 198.		

OPTICS.—PLATE III.

Fig. 1, a small portable camera obscura.	Fig. 4, p. 188.	Fig. 8, p. 291.
	Fig. 5, p. 188.	Fig. 9, p. 291.
	Fig. 6, p. 211.	Fig. 10, p. 286.
Fig. 2, p. 206.	Fig. 7, p. 212.	Fig. 12, p. 212.

OPTICS.—PLATE IV.

Fig. 1, p. 218.	Fig. 5, p. 219.	Fig. 9, p. 189.
Fig. 2, p. 218.	Fig. 6, p. 219.	Fig. 10, p. 291.
Fig. 3, p. 218.	Fig. 7, p. 219.	Fig. 11, p. 512.
Fig. 4, p. 218.	Fig. 8, p. 219.	Fig. 12, p. 512.
Fig. 5, p. 219.		

OPTICS.—PLATE V.

Fig. 1, p. 227.	Fig. 8, p. 222.	Fig. 14, p. 233.
Fig. 2, p. 227.	Fig. 9, p. 229.	Fig. 15, p. 234.
Fig. 3, p. 227.	Fig. 10, p. 230.	Fig. 16, p. 235.
Fig. 4, p. 228.	Fig. 11, p. 230.	Fig. 17, p. 235.
Fig. 5, p. 228.	Fig. 12, p. 231.	Fig. 18, p. 236.
Fig. 6, p. 228.	Fig. 13, p. 233.	Fig. 19, p. 236.
Fig. 7, p. 229.		

REFERENCES to the PLATES of VOL. II.

OPTICS.—PLATE VI.

Fig. 1, p. 245.	Fig. 7, p. 254.	Fig. 13, p. 379.
Fig. 2, p. 257.	Fig. 8, p. 364.	Fig. 13,* p. 485.
Fig. 3, p. 247.	Fig. 9, p. 363.	Fig. 14, p. 486.
Fig. 4, p. 28.	Fig. 10, p. 366.	Fig. 15, p. 493.
Fig. 5, p. 236.	Fig. 11, p. 372.	Fig. 16, p. 494.
Fig. 6, p. 252.	Fig. 12, p. 373.	Fig. 17, p. 384, 495.

OPTICS.—PLATE VII.

Fig. 2, p. 455.	Fig. 8, p. 503.	Fig. 13, p. 387.
Fig. 3, p. 486.	Fig. 9, p. 503.	Fig. 14, p. 390.
Fig. 4, 5, and 6, p. 488, 489.	Fig. 10, p. 507.	Fig. 15, p. 396.
Fig. 7, p. 500.	Fig. 11, p. 507.	Fig. 16, p. —
	Fig. 12, p. 387.	Fig. 17, p. 397.

OPTICS.—PLATE VIII.

Fig. 1, p. 513.	Fig. 5, p. 542.	Fig. 8, p. 549.
Fig. 2, p. 529.	Fig. 6, p. 546.	Fig. 9, p. 551.
Fig. 3, p. 534.	Fig. 7, p. 510.	Fig. 10, p. 546.
Fig. 4, p. 541.		

ERRATA in the FIGURES.

- Page 180, line 1, for fig. 12, pl. 2, read fig. 2, pl. 2.
 — 194, — 8, for fig. 15, pl. 2, read fig. 15,* because there
 are two fig. 15 in this plate.
 — 286, — 18, for fig. 1, read fig. 10, pl. 3.
 — 390, — 15, for fig. 11, pl. 7, read fig. 14, pl. 7.
 — 485, — 6, for fig. 13, pl. 6, read fig. 13,* pl. 6.

